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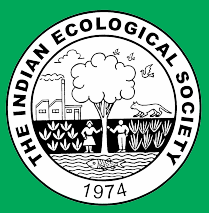

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Morphology, Genetic Relationships and Classification of Soils of Selected Micro-Watersheds in North-west India

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Abstract: Nine pedons representing the typical landforms of micro-watersheds in Chhachhrauli block of Yamunanagar, Haryana were exposed to determine the interrelationships and variability of soil characteristics. The colour of pedons was yellowish brown with dominant hue of 10YR. Soil structure was weak to strong, fine to medium, sub angular blocky across the pedons. The consistency of different pedons varied from non-sticky non-plastic to sticky plastic and soil texture varied from sand to loam with predominance of sand than clay in all the pedons. Bulk density, particle density and available water content across all the pedons varied from 1.01 to 1.75 Mg m^{-3}, 2.50 to 2.65 Mg m^{-3} and 1.01 to 16.38%, respectively. The pH ranged from 4.20 to 8.30 across all the profiles indicating acidic to alkaline nature of the soils. The soils were low to high in soil organic carbon (SOC). In all soils, SOC varied from 0.06 to 2.54 per cent and was higher in surface horizons than subsurface horizons. The $CaCO_3$ content in pedons 1, 3, 4, 5 and 6 was <1% suggesting nearly complete decalcification in these soils. The exchangeable complex of the soils was dominated by Ca followed by Mg, Na and K. Broadly the physiography and land use considerably influenced the value of total exchangeable bases. Relatively higher content of nutrients was observed in the surface horizons compared to subsurface horizons. The results demonstrated that, in general, varying SOC concentrations are associated with varying slope positions of the pedons, highlighting the significance of landform location in regulating soil water content as well as the SOC concentration. The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development. The soils of the study area were classified as sandy, mixed, hyperthermic, typic Ustipsamments (Pedon 1), fine loamy Ustochrepts (Pedon 2, 3, 5, 6, 7, 8 and 9) and coarse loamy Ustorthents (Pedon 4).

Keywords: Exchangeable bases, Landform, Micro-watershed, Nutrients, Pedon, Soil development

Soil is indispensable natural resource for sustaining life on the earth, therefore, appraisal of soil is imperative for determining productivity and resilience of the ecosystem (Satish et al 2018). The characterization of soil imparts the knowledge about morphological, physical, chemical, microbial and mineralogical characteristics of the soil which are immensely important for crop growth, nourishing forests and grasslands. Contrarily, soil classification aids to organize knowledge, exchange of experience and technology from place to place and helps in comparison of soil characteristics (Devi et al 2015). Soil is a unique natural resource and should be used prudently for sustainable development with minimum environmental risks. On the grounds of meagre knowledge about soil characteristics, soils are easily degraded due to misuse and mismanagement. The pedological assessment and classification of soils of a specific area is imperative for identification of its potential and limitations for increased and sustainable crop production. The purpose of soil characterization is to classify soils and measure physical and chemical characteristics, that could indicate the ability of the soil to function, not readily apparent from field study (Sanchez et al 2003). Therefore, the insight of soil involves marking its geographic location and extent besides discerning morphological, physico-chemical and fertility properties based on its geomorphic-soil relationship (Kharlyngdoh et al 2015).

Watershed is a naturally occurring hydrologic unit defined by natural boundaries, classified on the basis of geographical area, which carries runoff to a common point along a single waterway (Bhardwaj 2020, Sahoo et al 2021). Characterization of watershed can be utilised to determine the limitation and potentials of soil based on detailed information about the soil properties. Knowledge gained through characterization of soils can provide basic information to farmers and indigenous knowledge can be integrated with scientific approaches for the systematic management of watersheds. Based on the profile-wise information, soil management practices specific to that region can be recommended to farmers and other stakeholders for its judicious use. Consequently, this will lead to sustainable agriculture along with environmental protection (Mohammed et al 2017). Information on the type of soil, morphological, physical and chemical attributes of agricultural soils in Haryana, northwest India is essential for

strategic decision making and sustenance of land productivity. Therefore, it is important to carry out site-specific soil characterization in order to identify the existing heterogeneity of the soil system and generate adequate information to determine soil potential for proper soil management practices (Gorai et al 2013). Though, considerable work has been done in India and Haryana related to detailed soil survey but much of this information is available in the form of topographic maps and there is dearth of knowledge related to the land use of soils of many districts of Haryana. Moreover, information required for planning management practices for most efficient use of land resources is absent or scant in case of micro-watersheds. Besides, the information about the pedogenesis of soils at watershed scale in Haryana is available for selected areas only (Sahoo et al 2019, Sahoo et al 2021). At watershed scale, the topographic position of soils is considered for soil classification which is not only used to address land use management but also soil erosion and formation (Sadiq et al 2021). Watershed management is essential to agricultural practices because it enables the controlled use of water for irrigation as per the crop needs besides supplying water for a variety of other uses (Mahapatra et al 2019). Therefore, the present investigation was attempted to enhance our understanding about the morphology, genetic relationships and classification of soils of micro-watersheds in Chhachhrauli block of Yamunanagar, Haryana for developing better strategies for agricultural production and resource management.

MATERIAL AND METHODS

Site description: The micro-watersheds in Chhachhrauli block of Yamunanagar lie between 29° 55' 44" N and 30° 28' 34" N latitude and 77° 04' 20"E and 77° 36' 05" E longitude at an altitude of 274 meters with an average elevation of 258 meters above mean sea level. Major part of the Yamunanagar district is formed of alluvium rocks of Pleistocene age. Yamuna is the major river in the study area and Boli is a seasonal river. The soils of this region are sand to loamy sand in texture and has sub-tropical type monsoon climate and Chachhraulli is often termed as "Cherapunjii of Haryana" as it receives highest rainfall in whole Haryana and Punjab. The weather data of the study area is presented in Figure 1. The average rainfall in Haryana is 450mm during monsoon and Chachhraulli receives 1100 mm. The average annual temperature in the study area is 32°C with the highest in June (41°C) and minimum in January (9.1°C) thus qualifying for hyperthermic temperature regime. The district has a favourable climate for the growth of rich vegetation owing to reasonably good rainfall and elevation. Shisham (*Dalbergia sissoo*), kikar (*Acacia nilotica*), mango (*Mangifera indica*), jamun (*Syzgium cumini*), peepal (*Ficus religiosa*), badh (*Ficus bengalensis*), neem (*Azadirachta indica*), safeda (*Eucalyptus* hybrid) etc. are the important tree species grown in the area.

Soil Sampling and Analysis

Field methods: Before exposing soil pedons a reconnaissance survey was carried out in order to explore the representative observation sites. The field areas of villages Dadupur Jattan, Dhakwala, Kot, Fakirmajra, Fatehgarh forest, Yara forest, Arjun Majra, Kot Mushtarka and Mahab Aliwala were traversed thoroughly for field checks and the profile sites were delineated. In the field, based on morphological properties such as texture, roots, cutans, consistency, soil colour, pedon reaction, structure and concretions, different horizons were marked in each pedon. Nine soil profiles were exposed and studied morphologically in field by using FAO 2006 guidelines for soil profile description (FAO 2006). The soil samples of each profile were collected horizon-wise to study their physico-chemical properties in the laboratory.

Laboratory methods: Representative soil samples from each genetic horizon of the pedons were collected and dried in shade for laboratory analysis. The air-dried samples were ground with a wooden pestle and mortar and passed through 2 mm sieve to separate the coarse fragments (>2 mm) and through 0.5 mm sieve for chemical properties. Bulk density was determined by core method (Blake and Hartge 1965), moisture retention at 0.03 Mpa and 1.5 Mpa with Richard's pressure plate apparatus (Bruce and Luxmoore 1986), particle density by Pycnometer method (Means and Parcher 1963), mechanical analysis by International pipette method (Piper 1950) and infiltration rate measured in the field by using double ring close top infiltrometer (Reynolds 2002). Soil pH and EC was determined using pH meter and conductivity meter, respectively in 1:2 soil: water suspension (Jackson 1973). Organic carbon content was determined by wet digestion method (Walkley and Black 1934), available

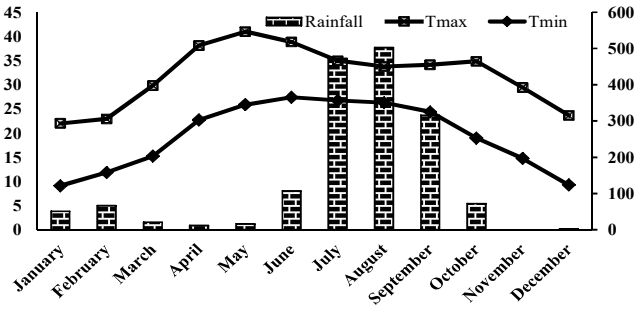

Fig. 1. Mean yearly weather data of the study area

nitrogen (N) by alkaline permanganate method (Subbaiah and Asija 1956), available P content by extracting the soil samples using 0.5M $NaHCO_3$ and analyzed by spectrophotometer (Olsen et al 1954). Available potassium was extracted with neutral normal ammonium acetate (pH 7.0) and the content of potassium in the solution was estimated by flame photometer (Jackson 1973). Calcium carbonate was estimated by rapid titration method (Puri 1949). Cation exchange capacity was determined in the extract obtained by leaching the soil with normal sodium acetate solution (pH 8.2) and sodium in the resultant extract was determined by flame photometer (Jackson 1973). Exchangeable calcium and magnesium were estimated by Versanate titration method (Cheng and Bray 1951) and micronutrients (Fe, Mn, Cu and Zn) by DTPA (Diethylene Triamine Penta Acetic acid) using atomic absorption spectrometer (Lindsay and Norvell 1978). Soils were classified according to Soil Taxonomy (Soil Survey Staff 2014).

Statistical analysis: The Statistical Package for the Social Sciences (SPSS) version 20.0 software (SSPS Inc., Chicago, IL, USA) was used to carry out the correlation of the data.

RESULTS AND DISCUSSION

The detailed characteristics of geomorphic units of micro-watersheds are presented in Table 1. Recent alluvial plain, old alluvial plain, piedmont plain and Shivalik hills were the four different physiographic units in the study area (Fig. 2). Slope, elevation, drainage conditions, location of the site, erosion and physiography control the soil formation process and thus regulate soil physico-chemical properties. Therefore, the study of soils, particularly in relation to landscape, is effective in explaining the natural factors and processes that have direct bearing on soil genesis (Sharma et al 2011). Seibert et al (2007) evinced that topography influences soil formation and different soil types are formed under distinct conditions.

Morphological characteristics: All the pedons were very deep except pedon 9 which was shallow (Table 2). The greater depth of the profile indicates prolonged weathering process which probably began under humid environments and slowed gradually with the present era moderate environmental conditions (Sharma et al. 2011). All the pedons had A-B-C horizons except pedons 5, 6 and 8 which exhibited A-C horizons. The absence of B horizon in pedons 5, 6 and 8 indicates lack of profile development. The B horizon in pedon 4 started at greater depth than B horizon in other pedons due to sola stability in the former. The distinctness of horizon boundary was abrupt to gradual between surface and subsurface horizons in all pedons with smooth topography, except in pedons 2, 5 and 8 where it was clear with wavy topography both in surface and subsurface horizons. The variations in nature of the horizon boundaries are the indications of the variability in the soil forming processes and impacts of anthropogenic activities (Cools and De-Vos 2010). Among the morphological properties, the most obvious feature of soil is colour and it is the most useful

Table 1. General characteristics of geomorphic units of studied area

Pedon No.	Physiography	Drainage	Erosion	Land use	Parent material	Slope (%)	Slope direction
1	Recent alluvial plain	Well drained	Moderate	Cultivated land (Wheat-Sugarcane rotation)	Alluvium	Very gently sloping (1-3%)	N-S
2	Piedmont plain	Well drained	Severe	Forest land (Dek, Bkain, Sheesham, Teak)	Alluvium	Moderately sloping (8-15%)	N-S
3	Old alluvial plain	Well drained	Moderate to nil	Cultivated land (Poplar)	Alluvium	Gently sloping (3-8%)	N-S
4	Recent alluvial plain	Well drained	Moderate	Cultivated land (Poplar)	Alluvium	Gently sloping (3-8%)	N-S
5	Piedmont plain	Imperfectly drained	Severe	Cultivated land (Kikar, Neem, Shrubs)	Alluvium	Moderately sloping (8-15%)	N-S
6	Shivalik hills	Moderately drained	Moderate	Forest land	Alluvium	Gently sloping (3-8%)	N-S
7	Old alluvial plain	Moderately drained	Moderate	Cultivated land (Ratoon Sugarcane)	Alluvium	Gently sloping (3-8%)	N-S
8	Old alluvial plain	Well drained	Low	Cultivated land (Fallow-Wheat in nearby fields	Alluvium	Near to very gently sloping (1-3%)	N-S
9	Old alluvial plain	Moderately drained	Nil	Cultivated land (Wheat)	Alluvium	Near to very gently sloping (1-3%)	N-S

property for identification and classification of soils. The colour of the studied pedons varied form dark yellowish brown to dark greyish brown with predominant hue of 10YR. The values ranged from 3 to 5, whereas chromas varied from 2 to 4. The low chroma is the indication of young nature of the parent material. The variation in the soil colour among different horizons could be due to variation in texture, topographic position, mineralogical, chemical composition, and soil moisture regimes (Dinesh et al 2017a). Broadly, surface horizons are darker in colour than sub-surface layers owing to high organic matter content in the top soil layers. Dinku et al (2014) also observed that the surface horizons are darker in colour than the subsurface horizons.

There was significant difference in the grade and size of the soil structure; however, more or less shape remained the same. By and large, structure of the surface pedons varied from weak medium sub angular blocky to moderate medium sub angular blocky while in the subsurface horizons the structure varied from moderate fine sub angular blocky to strong fine sub angular blocky which could be attributed to higher clay content and sufficient exposure to pedogenic processes in the subsurface horizons than surface horizons. Furthermore, the variation in soil structure is reflection of physiographic position of the pedons (Dinesh et al 2017a). The consistency of different pedons varied from non-sticky non-plastic to sticky plastic. The poor consistency of the studied pedons was due to sandy texture and indicates poor water holding characteristics of the soils. The greater variation in the soil consistency could be attributed to the differences in particle size distribution, predominantly clay content, organic matter and type of the clay particles. Moradi (2013) also evinced that soil consistence varied with soil texture. Mahapatra et al (2019) reported that soils of Buraka micro-watershed in Haryana were non-sticky to slightly sticky and non-plastic to slightly plastic in consistence. The roots in different pedons varied from very fine to coarse (size) and very few to common (quantity). Root biomass decreased with the depth because of reduction in biological activity, aeration and soil management effects. Uwingabire et al (2016) observed fine to coarse roots in the topsoil and few to common, medium to fine roots in subsoils of watershed divide. Coarse fragments were absent in pedons 7, 8 and 9 and formed a considerable volume in the pedons 1, 3, 4 and increased with depth except in pedons 2, 3 and 5 in which calcium carbonate concretions were present. Cutans were absent in all the profiles. The absence of cutans reflect that eluviation and illuviation were not the dominant pedogenic processes. Soil reaction with dilute HCl varied from no effervescence to strong effervescence thereby showing the presence of calcium carbonate which reflects the

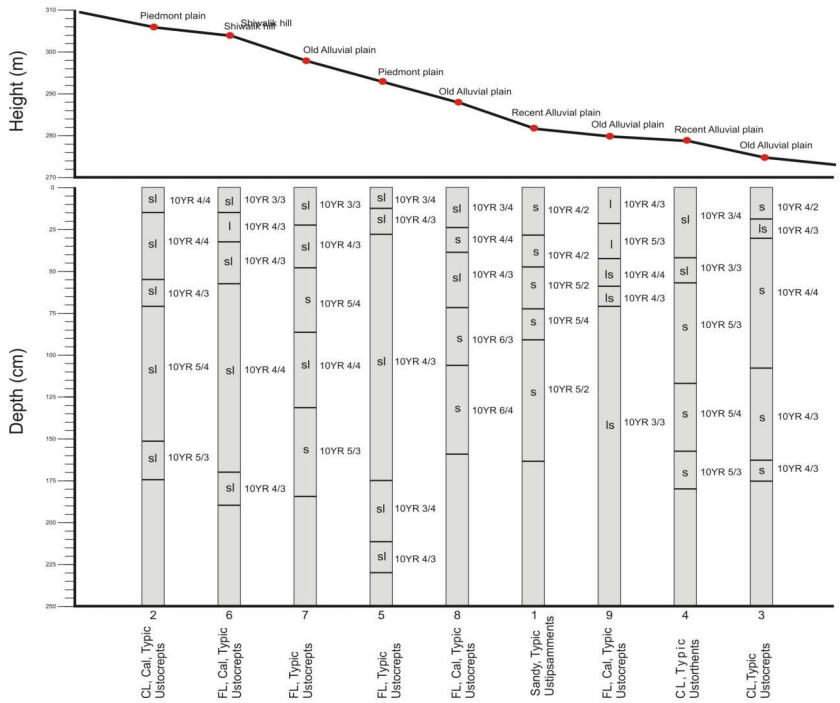

Fig. 2. Landscape-soil relationship of micro-watersheds of Chhachhrauli block of Yamuna Nagar

Table 2. Soil morphological characteristics of the studied pedons

Horizon	Depth (cm)	Horizon boundary	Colour (moist)	Structure	Consistence	Cutans	Roots	Coarse fragment	Reaction
Pedon-1									
Ap	0-28	a-s	10YR 4/2	1md sbk	NSNP	-	ffn	-	-
B1	28-47	c-s	10YR 4/2	1 md sbk	NSSP	-	-	<2%	-
B2	47-73	c-s	10YR 5/2	1 md sbk	NSSP	-	-	<5%	1
C1	73-91	c-s	10YR 5/4	1 md sbk	SSSP	-	-	>10% Pebbles	-
C2	91-164+	c-s	10YR 5/2	1 md sbk	SSNP	-	-	10% Pebbles	-
Pedon-2									
Ap	0-15	c-s	10YR 4/4	2 md sbk	SSSP	-	fc	<2%	-
B	15-55	c-s	10YR 4/4	2 md sbk	SSNP	-	fc	<1%	1
C1	55-71	c-w	10YR 4/3	2 md sbk	SSSP	-	-	<1%	1
C2	71-151	c-s	10YR 5/4	3 fn sbk	SP	-	-	<1%	2
C3	151-175+	c-s	10YR 5/3	2 md sbk	SSSP	-	-	<1%	1
Pedon-3									
Ap	0-19	c-s	10YR 4/2	1 md sbk	SSNP	-	fc	<1% Pebbles	-
B1	19-30	c-s	10YR 4/3	1 md sbk	NSNP	-	fc	<1% Pebbles	-
B2	30-108	c-s	10YR 4/4	1 md sbk	SSSP	-	-	-	-
C1	108-163	c-s	10YR 4/3	2 md sbk	SP	-	-	-	-
C2	163-175+	c-s	10YR 4/3	1 md sbk	SSSP	-	-	-	-
Pedon-4									
Ap	0-38	a-s	10YR 3/4	1 md sbk	SSSP	-	cfn	-	1
B	38-57	c-s	10YR 3/3	1 md sbk	SSSP	-	ffn	<1%	-
C1	57-117	c-s	10YR 5/3	1 md sbk	NSNP	-	-	>5%	-
C2	117-157	c-s	10YR 5/4	1 md sbk	NSNP	-	-	<2%	-
C3	157-180+	g-s	10YR 5/3	1 md sbk	NSNP	-	-	<1%	-
Pedon-5									
Ap	0-13	c-w	10YR 3/4	2 md sbk	SP	-	vffn	<1% concretion	1
C1	13-28	c-w	10YR 4/3	2 md sbk	SSSP	-	vffn	<1% Concretion	-
C2	28-175	g-s	10YR 4/3	1 md sbk	SSSP	-	vffn	-	-
C3	175-212	g-s	10YR 3/4	1 md sbk	SSNP	-	vffn	-	-
C4	212-230+	g-s	10YR 4/3	1 md sbk	SSSP	-	-	-	-
Pedon-6									
Ap	0-14	c-s	10YR 3/3	2 md sbk	SSSP	-	cfn	<1% concretion	-
C1	14-33	c-s	10YR 4/3	3 md sbk	SP	-	cfn	-	3
C2	33-57	g-s	10YR 4/3	2 md sbk	SSSP	-	ffn	-	-
C3	57-170	c-s	10YR 4/4	2 md sbk	SSSP	-	vffn	-	-
C4	170-190+	c-s	10YR 4/3	2 md sbk	SP	-	-	<1% Stones	-
Pedon-7									
Ap	0-22	a-s	10YR 3/3	2 md sbk	SP	-	ffn	-	1
B1	22-48	a-s	10YR 4/3	1 md sbk	SSSP	-	ffn	-	1
C1	48-86	c-s	10YR 5/4	1 md sbk	NSNP	-	ffn	-	-
C2	86-132	c-s	10YR 4/4	1 md sbk	SP	-	-	-	-
C3	132-184+	c-s	10YR 5/3	1 md sbk	SSSP	-	-	-	-
Pedon-8									
Ap	0-24	c-w	10YR ¾	1 md sbk	SP	-	cc	-	1
C1	24-38	c-w	10YR 4/4	2 md sbk	SSSP	-	ffn	-	1
C2	38-72	c-w	10YR 4/3	1 md sbk	SSSP	-	-	-	1
C3	72-106	g-s	10YR 6/3	1 co sbk	NSNP	-	-	-	-
C4	106-159+	g-s	10YR 6/4	1 co sbk	NSNP	-	-	-	-
Pedon-9									
Ap	0-21	a-s	10YR 4/3	1 md sbk	SSSP	-	mfn	-	1
B1	21-43	c-s	10YR 5/3	1 md sbk	SSSP	-	ffn	-	1
B2	43-59	a-s	10YR 4/4	1 md sbk	SSSP	-	-	-	1
C1	59-71	c-s	10YR 4/3	3 md sbk	SP	-	-	-	1
C2	71+	c-s	10YR 3/3	3 md sbk	SP	-	-	-	3

precipitation regime and leaching environment of these soils (Sahoo et al 2019).

Physical characteristics: The physical characteristics of the studied pedons are shown in Table 3. Particle size analysis revealed that sand, silt and clay content across the pedons varied from 50.12-95.53, 1.85-33.25 and 1.6-32.10%, respectively. Sand content, by and large, showed an increasing trend with soil depth and constituted the bulk of the mechanical fractions which may be assigned to siliceous nature of parent material. This kind of particle size distribution reflects slow weathering of the parent material. However, no consistent distribution pattern of silt was observed down the profile. The clay content exhibited an increasing trend with depth up to second horizon and thereafter decreased which could be due to the *in-situ* weathering of parent material or vertical migration of clay (Satish et al 2018). The textural class of soils of pedons 1 and 3 was sand whereas pedons 2, 4, 5, 6, 7, 8 were loam to sandy loam and pedon 9 loam to loamy sand in texture. The abrupt change in soil texture in pedon 8 and 9 indicated lithological discontinuity. Negative and significant correlation (r = 0.82) was observed between sand and clay content indicating that appreciable amount of clay has been formed due to weathering of sand (Sarmah et al 2019).

The particle density varied from 2.50 to 2.65 Mg m^{-3} across all the pedons and did not exhibit any regular trend with depth. Bulk density of all the pedons ranged from 1.01 to 1.75 Mg m^{-3} and increased with depth which may be ascribed to progressive compaction due to filling of pores by eluvial materials, lower organic matter, and less aggregation. It is well recognized that the variation in bulk density is due to differences in soil texture, organic matter content and management practices (Gülser et al 2016). Bulk density was negatively and significantly correlated with clay content (r = -0.60) and organic carbon (r = -0.67) which indicates that bulk density decreases with increasing clay content, partly because of increasing organic matter with the increment in clay content (Keller and Håkansson 2010). The pore space across the pedons ranged from 31.37 to 60.70% and decreased with soil depth which could be attributed to the lower organic matter in the lower depths and restricted penetration of crop roots into subsurface horizons. Moreover, this could be ascribed to high inter- and intra-aggregate voids as a result of high organic matter content and isovolumetric weathering (Chen et al 2001). A significant positive correlation was observed between pore space and clay (r = 0.60) and organic carbon (r = 0.68) but negative relationship with sand (r = -0.71; Table 4) suggesting that clay and organic matter were the principal factors that influenced pore space. Pore space was negatively correlated with bulk density (r = -0.99) but did not show any significant correlation with particle density thereby reflecting the influence of pore space on bulk density.

The variations in moisture retention at all the tensions are mostly linked to variations in soil texture. With increase in fineness of texture, water retention increased significantly which indicated that finer particles had greater effect on retention behaviour of soils as compared to sand content as explicated by the drainage that occurs when suction is increased from 0.03 to 1.5 Mpa. Variation in moisture retention with depth mostly followed the distribution pattern of clay at all the tensions. Water retained at field capacity and permanent wilting point varied from 3.91 to 37.45% and 1.17 to 21.07% across all the pedons, respectively. Water retention was significantly and positively correlated with pore space. The moisture retention at all the tensions was function of mechanical components of the soil which is manifested by highly positive and significant correlation between silt and clay and negative correlation of silt and clay with sand (Table 4). When suction pressure is increased from 0.03 to 1.5 MPa, macropores get emptied at once at lower suction range whereas micropores retain the water even at high suction pressure and predominantly the effect of clay can be seen due to greater number of micropores (Nikam et al 2006, Dinesh et al 2017a). Available water varied from 1.01-16.38% across the pedons and highest value was observed in Pedon 8. Almost 75% values of available water content were lower than 9.5 to 12.5%, values considered by FAO to support adequate plant growth (Sadiq et al 2021). The correlation between clay fraction and available water (r = 0.60) was significantly higher than the correlation of organic carbon (r = 0.57) indicating that increase in clay content increased water retention. However, significantly negative correlation was observed between sand and available water content (r = -0.64). Infiltration rate was very high (>1 cm hr^{-1}) in all the pedons which could be ascribed to sandy texture of the soils and higher organic carbon in the surface horizons. The hydraulic properties of soils, for instance, infiltration is influenced by soil texture; soil structure, especially shape and stability, pore space and size distribution and bulk density (Bhat et al 2022).

Chemical characteristics: Soil pH ranged from 4.2 to 8.3 across all the profiles indicating acidic to alkaline nature of the soils (Table 5). The highest value (8.3) was recorded in C3 horizon of pedon 8 and lowest (4.2) in surface horizon (Ap) of pedon 2. The acidic soil reaction was recorded in pedons 2, 5 and 6 which were under forest land use. The lower pH of some of these soils could be due to high organic matter content as the decomposition of OM releases organic acids thereby lowering the pH of the soil (Nega and Heluf

Table 3. Physical properties of the studied pedons

Pedon and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density	Particle density	Pore space (%)	Moisture retention		Available water (%)	Infiltration rate (mm hr^{-1})
		0.02-2.0 mm	0.002-0.02 mm	<0.002 mm		Mg m^{-3}			0.03 MPa	0.15 MPa		
Pedon-1												
Ap	0-28	89.26	4.60	5.90	Sand	1.40	2.57	45.52	7.9	3.92	3.98	27
B1	28-47	89.54	4.10	6.20	Sand	1.45	2.60	44.23	8.23	4.11	4.12	
B2	47-73	89.06	5.30	5.50	Sand	1.53	2.64	42.04	8.19	4.3	3.89	
C1	73-91	91.09	3.70	5.10	Sand	1.55	2.63	41.06	8.17	4.56	3.61	
C2	91-164+	92.02	3.6	4.30	Sand	1.59	2.52	36.90	6.5	3.3	3.2	
Pedon-2												
Ap	0-15	54.16	27.2	16.3	Sandy loam	1.07	2.61	59.00	29.1	18.6	10.5	21
B	15-55	54.92	25.5	17.8	Sandy loam	1.10	2.58	57.36	30.2	19.1	11.1	
C1	55-71	53.53	29.8	15.4	Sandy loam	1.14	2.56	55.46	28.7	19.8	8.9	
C2	71-151	54.79	30.4	13.9	Sandy loam	1.19	2.54	53.15	26.2	17.9	8.3	
C3	151-175+	53.33	32.3	12.7	Sandy loam	1.21	2.54	52.36	27.9	19.8	8.1	
Pedon-3												
Ap	0-19	88.41	8.86	2.10	Sand	1.10	2.57	57.19	6.21	3.2	3.01	25
B1	19-30	82.40	7.02	10.11	Loamy sand	1.16	2.61	55.55	7.31	3.87	3.44	
B2	30-108	89.66	5.70	4.40	Sand	1.25	2.56	51.17	7.19	5.14	2.05	
C1	108-163	94.08	3.50	2.20	Sand	1.32	2.54	48.03	6.12	4.16	1.96	
C2	163-175+	95.53	2.80	1.6	Sand	1.41	2.52	44.04	5.34	3.46	1.88	
Pedon-4												
Ap	0-38	52.32	30.83	15.5	Sandy loam	1.27	2.57	50.58	26.27	17.7	8.57	20
B	38-57	50.12	32.2	16.2	Sandy loam	1.29	2.61	50.57	27.29	18.2	9.09	
C1	57-117	87.95	5.70	5.90	Sand	1.42	2.56	44.53	6.12	4.05	2.07	
C2	117-157	91.25	3.70	4.90	Sand	1.44	2.54	43.30	5.71	3.7	2.01	
C3	157-180+	94.10	1.85	3.80	Sand	1.46	2.54	42.51	3.91	2.9	1.01	
Pedon-5												
Ap	0-13	50.61	30.8	16.5	Sandy loam	1.12	2.57	56.42	26.2	14.7	11.5	21
C1	13-28	50.25	30.2	17.3	Sandy loam	1.18	2.61	54.78	27.3	15.1	12.2	
C2	28-175	52.90	29.5	15.8	Sandy loam	1.23	2.56	51.95	24.9	14.2	10.7	
C3	175-212	51.70	32.2	15.0	Sandy loam	1.27	2.63	51.71	23.4	13.3	10.1	
C4	212-230+	54.45	29.8	14.8	Sandy loam	1.32	2.65	50.18	21.9	12.6	9.3	
Pedon-6												
Ap	0-14	50.78	31.25	16.1	Sandy loam	1.10	2.57	57.19	24.6	13.4	11.2	18
C1	14-33	51.28	16.8	30.5	Loam	1.14	2.55	55.29	35	19.1	15.9	
C2	33-57	50.49	30.70	17.80	Sandy loam	1.17	2.56	54.29	10.44	4.1	6.34	
C3	57-170	51.77	32.30	15.10	Sandy loam	1.20	2.52	52.38	17.87	10.3	7.57	
C4	170-190+	54.46	31.52	13.70	Sandy loam	1.24	2.54	51.18	16.73	9.8	6.93	
Pedon-7												
Ap	0-22	53.78	30.10	15.10	Sandy loam	1.01	2.57	60.70	18.93	7.13	11.8	
B1	22-48	50.96	31.80	16.40	Sandy loam	1.09	2.61	58.23	20.11	7.4	12.71	
C1	48-86	88.55	5.70	4.80	Sand	1.26	2.56	50.39	8.53	3.3	5.23	
C2	86-132	51.22	33.25	15.00	Sandy loam	1.29	2.55	49.21	7.81	3.28	4.53	
C3	132-184+	90.82	2.10	6.85	Sand	1.33	2.58	47.84	5.24	1.5	3.74	

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Table 3. Physical properties of the studied pedons

Pedon and Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density	Particle density	Pore space (%)	Moisture retention		Available water (%)	Infiltration rate (mm hr^{-1})
		0.02-2.0 mm	0.002-0.02 mm	<0.002 mm		Mg m^{-3}			0.03 MPa	0.15 MPa		
Peodn-8												
Ap	0-24	53.34	30.75	15.10	Loam	1.03	2.57	59.92	36.11	20.55	15.56	12
C1	24-38	52.29	16.66	30.5	Loam	1.14	2.61	56.32	37.45	21.07	16.38	
C2	38-72	90.51	4.75	4.4	Sand	1.26	2.56	50.78	7.12	1.17	5.95	
C3	72-106	89.90	7.1	2.90	Sand	1.45	2.54	42.91	7.16	3.82	3.34	
C4	106-159+	90.15	5.3	3.2	Sand	1.75	2.55	31.37	6.04	3.65	2.39	
Pedon-9												
Ap	0-21	58.2	10.24	30.80	Loam	1.18	2.57	54.08	16.67	10.32	6.35	15
B1	21-43	59.9	7.59	32.10	Loam	1.21	2.51	51.79	20.6	13.37	7.23	
B2	43-59	80.76	6.34	12.70	Loamy sand	1.29	2.52	48.80	15.38	11.13	4.25	
C1	59-71	84.82	3.81	11.20	Loamy sand	1.35	2.50	46.00	13.44	10.05	3.39	
C2	71+	86.48	2.91	10.50	Loamy sand	1.41	2.59	45.55	12.71	10.98	1.73	

Table 4. Correlation matrix among physico-chemical properties

Soil property		Sand	Silt	Clay	BD	PD	PS	Moisture retention		Available water	OC	CEC
								0.03 MPa	1.5 MPa			
Sand		1										
Silt		-0.93**	1									
Clay		-0.82**	0.58**	1								
BD		0.70**	-0.63**	-0.60**	1							
PD		-0.21	0.23	0.11	-0.09	1						
PS		-0.71**	0.64**	0.60**	-0.99**	0.21	1					
Moisture retention	0.03 MPa	-0.65**	0.57**	0.62**	-0.57**	0.12	0.57**	1				
	1.5 MPa	-0.60**	0.52**	0.58**	-0.48**	0.07	0.48**	0.96**	1			
Available water		-0.64**	0.57**	0.59**	-0.62**	0.19	0.63**	0.92**	0.78**	1		
OC		-0.69**	0.66**	0.51**	-0.67**	0.25	0.68**	0.55**	0.48**	0.58**	1	
CEC		-0.66**	0.60**	0.60**	-0.48**	0.39**	0.52**	0.49**	0.44**	0.49**	0.686**	1

** Significant at 0.01 probability level; * Significant at 0.05 probability level

2013, Dinesh et al 2020). Moreover, this could be substantiated by negative and highly significant correlation between pH and organic carbon (r = -0.86; Table 6). Generally, it was observed that surface layers have lower pH than sub-surface horizons which can be ascribed to accretion of H^+ and Al^{3+} ions released from biochemical weathering or it could be due to leaching of exchangeable bases from upper layers under high rainfall (Gogoi et al 2018). Electrical conductivity of all the pedons varied from 0.03 to 0.23 dS m^{-1} indicating non saline nature of the soils. However, EC did not exhibit any trend with the depth. Satish et al (2018) evinced that well drained conditions of soil help in removing excess of salts by the percolating and drainage water thereby resulting in lower EC.

The soils were low to high in organic carbon. Across all the soils, organic carbon varied from 0.06 to 2.54 per cent and was higher in surface horizons than subsurface horizons. The results showed that organic carbon content was less under cultivated land (0.06%) than forest land (2.54%). This variation among the soils could be ascribed to the differences in vegetation cover, land use and human activities among the sites. Moreover, the higher organic carbon in the pedons 1, 8 and 21 might be attributed to the abundance of slow decomposition compounds like lignin of organic matter as these pedons are under forest cover. Organic carbon was positively and significantly correlated with clay (r = 0.51) and silt content (r = 0.66) whereas negatively correlated with sand (r = -0.69;). This relationship could be adduced to higher

Table 5. Chemical characteristics of the studied pedons

Pedon and Horizon	Depth (cm)	pH (1:2)	EC (dS m^{-1})	OC %	CaC O_3	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	ESP	BSP	N	P	K	Zn	Fe	Cu	Mn
						cmol (+)kg^{-1}							kg ha^{-1}			mg kg^{-1}			
Pedon-1																			
Ap	0-28	8.0	0.07	0.24	Nil	2.50	1.00	0.47	0.21	5.82	8.07	71.82	173	19	227	0.41	4.01	0.17	0.84
B1	28-47	7.9	0.07	0.16	Nil	2.00	0.50	0.26	0.17	6.56	3.96	44.66	157	14	198	0.34	3.77	0.13	0.55
B2	47-73	8.0	0.12	0.14	0.50	1.70	0.50	0.26	0.15	5.78	4.49	45.15	125	11	177	0.28	3.20	0.07	0.48
C1	73-91	8.1	0.08	0.11	Nil	1.00	0.50	0.34	0.20	4.84	7.02	42.14	94	9	163	0.27	2.95	0.05	0.32
C2	91-164+	8.0	0.05	0.08	0.63	1.00	0.50	0.17	0.25	2.97	5.72	64.64	78	5	152	0.25	1.78	0.02	0.11
Pedon-2																			
Ap	0-15	4.2	0.07	2.34	Nil	4.70	2.30	0.56	0.38	8.92	6.28	89.01	188	20	431	0.48	4.63	1.60	5.27
B	15-55	5.1	0.07	1.78	0.62	3.00	1.50	0.61	0.64	7.11	8.58	80.87	157	16	312	0.46	4.56	1.22	4.05
C1	55-71	5.1	0.10	1.27	1.00	3.50	0.50	0.69	0.35	6.50	10.62	77.54	125	13	170	0.42	3.61	1.01	3.87
C2	71-151	5.5	0.13	0.91	4.05	3.00	0.50	0.75	0.38	5.56	13.49	83.27	94	19	143	0.39	3.05	0.80	3.48
C3	151-175+	5.9	0.10	0.67	0.87	1.50	1.00	0.62	0.35	4.44	13.96	78.15	78	5	124	0.34	2.93	0.50	2.71
Pedon-3																			
Ap	0-19	7.6	0.05	0.63	Nil	1.00	0.50	0.56	0.15	5.14	10.89	43.00	204	18	275	0.94	4.59	0.20	0.84
B1	19-30	7.5	0.03	0.47	Nil	4.50	1.50	0.47	0.12	6.98	6.73	94.41	173	15	141	0.88	4.35	0.17	0.67
B2	30-108	7.4	0.08	0.24	Nil	0.70	0.30	0.30	0.85	4.71	6.37	45.65	125	11	124	0.81	3.32	0.11	0.25
C1	108-163	7.5	0.04	0.22	Nil	1.75	0.65	0.49	0.46	3.55	13.80	94.37	86	8	105	0.75	2.19	0.07	0.14
C2	163-175+	7.9	0.09	0.07	Nil	0.55	0.23	0.37	0.21	2.79	13.26	48.75	70	5	88	0.63	0.12	0.03	0.06
Pedon-4																			
Ap	0-38	7.6	0.14	1.48	0.50	5.00	2.00	0.61	0.30	10.04	6.08	78.78	212	19	170	0.95	8.11	0.48	1.96
B	38-57	7.3	0.09	1.38	Nil	5.50	2.00	0.68	0.53	10.23	6.65	85.14	204	17	133	0.89	6.58	0.33	1.08
C1	57-117	7.3	0.03	0.45	Nil	0.34	0.16	0.17	0.17	1.20	14.17	70.00	173	12	105	0.81	5.29	0.21	0.42
C2	117-157	7.2	0.11	0.15	Nil	0.14	0.23	0.25	0.30	1.89	13.23	48.68	141	10	57	0.72	4.17	0.18	0.11
C3	157-180+	7.8	0.14	0.30	Nil	1.50	0.50	0.35	0.33	3.89	9.00	68.89	110	6	19	0.65	3.87	0.11	0.91
Pedon-5																			
Ap	0-13	4.3	0.09	2.25	0.50	5.00	2.50	1.08	0.53	10.54	10.25	86.43	236	18	275	0.91	9.86	0.47	4.97
C1	13-28	4.4	0.05	2.09	Nil	6.00	1.60	0.53	0.56	15.01	3.53	87.21	204	15	190	0.88	9.32	0.41	4.94
C2	28-175	4.7	0.03	1.80	Nil	4.00	1.50	0.39	0.79	7.48	5.21	89.30	169	13	135	0.79	9.06	0.35	4.92
C3	175-212	5.3	0.04	1.10	Nil	3.00	2.00	0.26	0.84	7.10	3.66	85.92	110	10	111	0.71	8.26	0.26	4.17
C4	212-230+	5.9	0.04	0.95	Nil	2.70	1.50	0.26	0.84	6.10	4.26	86.89	78	8	95	0.68	5.23	0.21	3.80
Pedon-6																			
Ap	0-14	5.9	0.05	1.87	Nil	3.50	0.80	0.95	0.51	9.40	10.11	61.28	243	17	181	0.88	8.09	0.55	5.38
C1	14-33	6.1	0.11	1.42	4.50	4.30	1.10	0.91	0.23	10.10	9.01	64.75	220	15	170	0.76	6.78	0.48	5.17
C2	33-57	6.4	0.07	1.01	Nil	3.10	0.50	0.69	0.51	7.60	9.08	63.16	196	12	162	0.70	6.26	0.36	5.01
C3	57-170	6.7	0.08	0.83	Nil	2.40	1.10	0.71	0.30	7.30	9.73	61.78	153	10	157	0.65	6.15	0.24	4.34
C4	170-190+	7.0	0.07	0.32	Nil	2.40	1.10	0.17	0.35	6.70	2.54	60.00	94	7	67	0.56	4.92	0.12	4.07
Pedon-7																			
Ap	0-22	6.3	0.23	1.02	0.35	2.00	0.20	0.66	0.35	4.56	14.47	70.39	195	19	227	0.90	8.33	0.45	4.42
B1	22-48	6.0	0.19	0.84	0.50	3.03	1.13	0.73	0.38	6.58	11.09	80.09	173	15	200	0.86	7.14	0.38	4.14
C1	48-86	6.2	0.10	0.69	Nil	1.00	0.50	0.47	0.38	3.41	13.78	68.91	157	13	143	0.74	5.17	0.32	3.49
C2	86-132	7.3	0.23	0.52	Nil	1.50	0.30	0.68	0.69	4.67	14.56	67.88	70	10	133	0.66	3.61	0.29	3.46
C3	132-184+	7.1	0.20	0.23	Nil	1.70	0.80	0.57	0.51	4.01	14.21	89.28	62	8	68	0.61	1.84	0.16	3.28

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Table 5. Chemical characteristics of the studied pedons

Pedon and Horizon	Depth (cm)	pH (1:2)	EC (dS m^{-1})	OC %	$CaCO_3$	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	ESP	BSP	N	P	K	Zn	Fe	Cu	Mn
						Cmol (+)kg^{-1}							kg ha^{-1}			mg kg^{-1}			
Pedon-8																			
Ap	0-24	7.6	0.16	0.81	0.50	0.60	1.40	0.54	0.38	4.33	12.47	67.44	212	18	300	0.52	4.53	0.19	1.11
C1	24-38	8.0	0.12	0.55	0.75	3.00	2.00	0.56	0.30	6.86	8.16	85.42	188	13	252	0.47	4.15	0.14	0.96
C2	38-72	7.9	0.12	0.34	1.25	1.50	0.50	0.61	0.30	4.23	14.42	68.79	141	10	161	0.31	3.93	0.12	0.75
C3	72-106	8.3	0.06	0.10	Nil	2.00	1.50	0.39	0.12	4.56	8.55	87.94	110	6	145	0.22	3.53	0.05	0.62
C4	106-159+	8.2	0.07	0.06	Nil	1.00	0.50	0.34	0.12	2.46	13.82	79.67	78	4	105	0.14	2.41	0.08	0.22
Pedon-9																			
Ap	0-21	7.6	0.1	0.8	0.1	2.5	0.5	0.4	0.2	4.1	9.5	87.9	212	18	259	0.63	5.28	0.91	1.78
B1	21-43	7.8	0.1	0.4	0.2	3.2	1.7	0.5	0.3	6.9	7.5	83.0	188	12	212	0.54	4.66	0.89	0.80
B2	43-59	7.8	0.1	0.2	0.5	1.9	0.5	0.6	0.4	4.3	14.1	78.8	125	11	190	0.26	3.55	0.78	0.46
C1	59-71	7.6	0.2	0.2	0.8	1.5	0.4	0.5	0.4	4.2	12.4	67.0	110	9	165	0.19	2.65	0.41	0.26
C2	71+	7.8	0.2	0.1	4.5	1.1	0.5	0.4	0.2	3.6	10.8	60.8	78	7	143	0.05	1.12	0.20	0.25

Table 6. Correlation matrix among physico-chemical properties

Soil property	pH	EC	OC	$CaCO_3$	CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	ESP	BSP	Sand	Silt	Clay
pH	1													
EC	0.37*	1												
OC	-0.86**	-0.17	1											
$CaCO_3$	-0.33*	0.32*	0.08	1										
CEC	-0.61**	-0.18	0.69**	0.05	1									
Ca^{2+}	-0.60**	-0.19	0.65**	0.03	0.92**	1								
Mg^{2+}	-0.45**	-0.20	0.48**	-0.05	0.62**	0.55**	1							
Na^{+}	0.22	0.27	0.29	0.13	0.31*	0.20	0.25	1						
K^{+}	-0.50**	-0.12	0.45**	-0.17	0.30*	0.25	0.26	0.09	1					
ESP	0.16	0.37*	-0.19	0.04	-0.38*	-0.35*	-0.30*	0.60**	-0.09	1				
BSP	-0.33*	0.04	0.31*	-0.01	0.19	0.39**	0.50**	0.43**	0.26	0.32*	1			
Sand	0.59**	-0.03	-0.69**	-0.16	-0.66**	-0.58**	-0.55**	-0.37*	-0.44**	0.14	-0.36*	1		
Silt	-0.61**	0.10	0.66**	0.04	0.60**	0.51**	0.48**	0.41**	0.50**	-0.06	0.31*	-0.93**	1	
Clay	-0.39**	0.10	0.51**	0.33*	0.60**	0.52**	0.54**	0.23	0.25	-0.20	0.28	-0.82**	0.58**	1

surface area of fine silt and clay fractions that results in the formation of organo-mineral complexes which protect carbon form microbial oxidation. Moreover, organic matter decomposes more rapidly in sandy soil as compared to clayey soil (Zhang and Liu 2010). In addition, the findings demonstrated that varying SOC concentrations are associated with varying slope positions of the pedons, highlighting the significance of landform location in regulating soil water content was well as the SOC concentration. Calcium carbonate ($CaCO_3$) content across all pedons but pedon 3 ranged from 0.12 to 4.50% showing an increase with increasing soil depth. The relatively higher concentration of $CaCO_3$ in the subsurface than the surface horizons can be attributed to the leaching effect and calcitic parent material. The $CaCO_3$ content in pedons 1, 3, 4, 5 and 6 was <1% suggesting nearly complete decalcification in these soils. Satish et al (2018) adduced that the downward movement of calcium and its subsequent precipitation as carbonate and/ or decomposition of calcium carbonate is responsible for higher $CaCO_3$ at lower depths. Negative correlation was observed between $CaCO_3$ and P (r = -0.12) which can be due to fixation of P as calcium phosphate and $CaCO_3$ and pH (r = 0.13) because higher pH causes the saturation of calcium carbonate (Bhat et al 2017).

The exchangeable bases exhibited non-uniform trends as a result of variations in soil depth and topographic position (Table 5). The exchangeable complex of the soils was dominated by Ca followed by Mg, Na and K which is in

agreement with the findings of Sadiq et al (2021). Exchangeable Ca with values ranging between 1.00 to 2.50 cmol (p^+) kg^{-1} dominated other cations sites which could be adduced to its affinity for exchange sites or as a result of calcium bearing parent material (Nahusenya et al 2014). Exchangeable Mg was medium to high (Landon 1991) and overall exhibited an increasing trend with depth up to second horizon and thereafter decreased with depth which could be ascribed to higher clay content in these horizons which contributes easily to the retention of Mg^{2+}. The significant and positive correlation between clay and Ca^{2+} (r = 0.52; Table 6) and Mg^{2+} (r = 0.54) reveals that clay contributed to the retention of divalent cations. Exchangeable Na and K varied between 0.17 to 1.08 cmol (p^+) kg^{-1} and 0.12 to 0.85 cmol (p^+) kg^{-1}, respectively across the pedons and exhibited irregular distribution with soil depth. The variation in exchangeable cations across the pedons might also be due to the preferential adsorption of divalent cations over monovalent cations on the variable negative charges on soil organic matter surfaces as well as limited development of the charge sites in the sandy soil (Yusoff et al 2017).

The CEC, by and large, was low and varied from 1.20 to 15.01 cmol (p^+) kg^{-1} in all the pedons and decreased with increase in depth due to decrease in organic matter and lower clay content in underlying horizons with an increase in sand proportion (Mandal 2014). Dinesh et al (2017b) evinced that low CEC of the soils could be due to the dominance of illite or low charge minerals besides low organic matter. Cation exchange capacity was higher in pedons 2, 5, 6 because these soils were under forests having high organic matter. A significant positive correlation was observed between CEC and clay (r = 0.60), CEC and OC (r = 0.69) whereas negative correlation was observed between CEC with sand (r = -0.66) which suggest that colloidal fractions were key factors that influenced CEC. Bhat et al (2017) also reported positive relationship between colloidal fractions and CEC of the soils of Gohana Haryana. Broadly the physiography and land use considerably influenced the value of total exchangeable bases. The exchangeable sodium percentage varied from 2.54 to 14.56% indicating the non-sodic nature of the soils and followed irregular pattern with the increase in depth. The lower ESP in soils could be adduced to masking effect of Ca and Mg *vis a vis* Na on exchange complex whereas the higher ESP in some horizons could be attributed to precipitation of Ca by carbonates, bicarbonates and hydroxide ion concentrations in the soil. These results are affirmed by the significant and positive relationship between ESP and Na ions (r = 0.60) while a negative correlation of ESP with Ca (r = -0.35) and Mg (r = -0.30). The base saturation percentage was medium to high (Landon 1991) and ranged from 42.14 to 94.41% across all the pedons. Base saturation percentage exhibited an irregular distribution pattern with soil depth. Calcium, Mg, Na and pH significantly influenced the base saturation percentage of the soil. The differences in CEC, base saturation and water retention properties among the soils could be attributed largely to the type and content of the soil colloids and soil pH values (Sharma et al 2011). The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development.

Amongst the available macronutrients, nitrogen was low and varied from 62 to 243 kg ha^{-1}. The availability of nitrogen was high in surface horizons and decreased with increase in

Table 7. Correlation matrix among nutrients and physico-chemical properties

Soil property	N	P	K	Zn	Cu	Mn	Fe	OC	$CaCO_3$	pH	Sand	Silt	Clay
N	1												
P	0.75**	1											
K	0.60**	0.61**	1										
Zn	0.67**	0.63**	0.52**	1									
Fe	0.40**	0.34*	0.57**	0.16	1								
Mn	0.56**	0.26	0.31*	0.44**	0.45**	1							
Cu	0.73**	0.53**	0.42**	0.33*	0.47**	0.64**	1						
OC	0.54**	0.29*	0.53**	0.55**	0.22*	0.55**	0.39**	1					
$CaCO_3$	-0.03	-0.22*	0.06	-0.01	-0.09	0.07	-0.05	0.08	1				
pH	-0.26	-0.03	-0.28	-0.41**	-0.10	-0.41**	-0.12	-0.86**	-0.33*	1			
Sand	-0.46**	-0.17	-0.36*	-0.27	-0.17	-0.62**	-0.55**	-0.69**	-0.16	0.59**	1		
Silt	0.32*	0.13	0.25	0.22	0.02	0.53**	0.42**	0.66**	0.04	-0.61**	-0.93**	1	
Clay	0.47**	0.11	0.36*	0.23	0.27	0.56**	0.50**	0.51**	0.33*	-0.39**	-0.82**	0.58**	1

depth which might be due to decreased organic carbon content with increasing depth and prevailing high temperature. Nitrogen showed significant and positive correlation with organic carbon (r = 0.54) indicating that N is closely linked with organic matter. The positively significant relationship between nitrogen and clay (r = 0.47) and negatively significant correlation with sand content (r = -0.45) indicated that the finer fractions influence the availability of nitrogen than coarser fractions. A positive and significant correlation was observed among N, P and K which suggests the synergistic effect. The significant relation of N with OC, N, P and K is similar to the findings reported by Dinesh et al (2020). Available phosphorous was low to medium and varied from 4 to 20 kg ha^{-1}. The pedons under forested land use had higher available P as compared to agriculture land use. Available phosphorous decreased with the increase in depth which might be due to the external application of phosphatic fertilizers in soils under cultivation and higher organic matter in the surface horizons of the pedons under forest land use. The results agree with those of Sahoo et al (2020) who reported higher available P content in the surface horizons of different pedons. Positively significant correlation between P and OC (r = 0.29) indicates that organic matter serves as reservoir of available P. This could be adduced to the synthesis of easily accessible organophosphate complexes, acidulation effect of organic matter, phosphorus release from organic complexes and reduced phosphorus fixation by humus through formation of iron and aluminium oxide coatings (Sadiq et al 2021). Available potassium varied from 19 to 431 kg ha^{-1} and showed decreasing trend with the soil depth. Available K was medium to high across all the pedons. The higher content of K in surface horizons could be due to greater exposure of surface soil to weathering agencies at surface than subsurface thereby resulting in higher release of potassium in surface soils. The correlation analysis showed that available K exhibited positive and significant correlation with organic carbon (r = 0.53) and clay (r = 0.36) due to the availability of enough exchange sites and high specific surface area while sand and available K were negatively correlated (r = -0.36). The results agree with those of Dinesh et al (2020) who reported positive and significant correlation between available K and OC and clay. Reza et al (2014) reported that available potassium increases with increase in clay and silt due to presence of potassium bearing minerals like feldspars, illite, mica in clay and silt fractions. However, available K was negatively correlated with sand which may be due to presence of quartz which is the dominant mineral in the sand fraction and does not retain K.

The DTPA extractable Zn content varied from 0.05 to 0.95 mg kg^{-1} across the pedons. Considering 0.6 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Zn for normal plant growth, it was observed that surface horizons of all the pedons except pedon 8 were sufficient in zinc content. Zinc exhibited a decreasing distribution pattern down the profile which could result from biomining and turnover by plant residues (Dinesh et al 2020). The distribution pattern of DTPA extractable Zn in these profiles suggests that during the early stages of soil development the pedochemical weathering of soils released zinc from soil minerals. Portion of the released Zn combined with clay by strong adsorption on the surface and some part got complexed with organic matter. However, complex formation with organic matter was more dominant as evinced by significant and positive correlation (r = 0.55). The DTPA extractable Fe content ranged from 0.12 to 9.86 mg kg^{-1} across all the pedons. Considering 4.5 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Fe for normal plant growth, it can be inferred that soils of the study area were sufficient in Fe except pedon 1 and lower horizons of few pedons. Relatively higher content of available iron was observed in the surface horizons compared to subsurface horizons which could be adduced to mobility of Fe in the soil. The mobility of Fe is governed by its redox potential and several soil characteristics such as pH, organic matter and moisture regimes (Sharma and Jassal 2013). The DTPA extractable Cu content varied from 0.02 to 1.60 mg kg^{-1} across all the pedons. Considering 0.2 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Cu for normal plant growth, it can be adduced that all pedons were high in Cu content except pedons 1 and 7. Relatively higher content of available Cu was observed in the surface horizons compared to subsurface horizons which could be ascribed to higher OC in surface horizons as Cu is strongly complexed with organic matter even to a greater extent than other micronutrients (Sharma et al 2015). The DTPA extractable Mn content varied from 0.06 to 5.38 mg kg^{-1} across all the pedons. Considering 2.5 mg kg^{-1} (Lindsay and Norvell 1978) as the critical limit of DTPA extractable Mn for normal plant growth, it is observed that all surface horizons were high in Mn content except pedons 1, 3, 4, 8 and 9. It was high in the surface horizons and gradually decreased with depth which might be due to higher biological activity and organic carbon in the surface horizons. Manganese was positively and significantly correlated with clay (r = 0.56) indicating that fine textured soils had higher Mn compared to coarse textured soils which may be due to higher adsorption and retention of Mn by finer fractions (Dinesh et al 2020).

Soil classification: The soils under study were classified in accordance with USDA Soil Taxonomy (Soil Survey Staff 2014). Based on climate variation, geomorphic position,

morphology, physico-chemical characteristics, the soils of the study area were classified into different orders. Soil moisture regime is a function of climate, soil and landform and it is important for not only understanding pedogenesis and nutrient availability, but also in the classification of soil at different categoric levels, such as Soil Family and Suborder. There are two dominant kinds of soil moisture regimes based on rainfall, evaporation and geomorphic position. The soils of the watershed were grouped into two moisture regimes *i.e*., Ustic (rainfall 300-1000mm) and Udic (rainfall >1000 mm). Based on soil temperature and mixed minerals the soils were placed under hyperthermic (22° to < 28°) and mixed mineralogy family, respectively.

The soils of pedons 2, 3, 5, 6, 7 and 9 were placed under the order Inceptisols whereas pedons 1, 4 and 8 were classified as Entisols. The soils under Entisols were immature, lacked pedogenic development and horizon differentiation. The soils of the pedon 1, 4 under the order Entisols were formed from recent alluvial parent material. Pedon 1 was placed under great groups of Ustipsamments due to presence of ustic soil moisture regime in this area. Entisols that are coarse-textured, have excessive drainage, low available water-holding capacity and would need frequent and lighter irrigation are placed under suborder Psamments. Pedon 4 was placed under suborder Orthents because this pedon was better drained and show regular decrease of organic matter with depth. The soils of the pedon 2, 3, 5, 6, 7, 8 and 9 were placed under the order Inceptisol formed from old alluvial parent material and suborder Ustochrepts because they have ustic soil moisture regime. Dinesh et al (2017a) classified soils of north-eastern Haryana into Entisols and Inceptisols as the former lacked pedogenic development and latter had cambic subsurface horizons.

CONCLUSION

The different landscape positions alongside variation in land use substantially determine differences in morphological, physical, and chemical properties of soils in the selected micro-watersheds of Chhachhrauli block of Yamuna Nagar, Haryana. The geomorphic location of each pedon across the watersheds has influenced strongly the movement of solutes and therefore soil development. By and large, the morphological, physical and chemical characteristics of the soils indicate a moderate stage of soil development, which is characteristic of Inceptisols. The soils were classified into two soil orders that is Entisols and Inceptisols on the basis of soil properties. The study reveals the significance of soil characterization and classification for understanding similarities and relationship among soil attributes for better agronomical evaluation within the region.

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Evaluation of Spatial Variability and Irrigation Water Quality of Groundwater in Prakasam District of Andhra Pradesh

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***Abstract*:** A study was conducted in the year 2021 to evaluate spatial variability and irrigation water quality of groundwater in Praksam district, Andhra Pradesh. Representative 261 samples with GPS locations were collected. The groundwater samples were analyzed for pH, EC, Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}; CO_3^{-2}, HCO_3^{-}, $Cl^{-}$and SO_4^{-2}. The pH, electrical conductivity, SAR and RSC of groundwater ranged from 6.6-9.1, 0.5-31 (dSm^{-1}), 0.42-40.6 $(mmol\ l^{-1})^{1/2}$, -146 -19.4 ($me\ l^{-1}$). The concentration of cations *viz.,* Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} varied from 0.8-48.0, 0.4-105, 0.7-355 and 0.004-30.04meq l^{-1}. Anions viz., CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2} varied from 0.0-1.4, 1.6-21.8, 0.8-318 and 0.21-17.08 meq L^{-1}. Abundance of ions in ground water samples were Na^{+}> Mg^{+2}>Ca^{+2}> K^{+} for cations and HCO_3^{-}>Cl^{-}> SO_4^{-2}> CO_3^{-} for anions. According to CSSRI classification of irrigation water, 37.16, 27.20, 2.29, 8.81, 9.19, 6.89 and 8.42 per cent samples were good, marginally saline, Saline, High SAR Saline, marginally alkaline, alkali and highly alkali, respectively. Spatial variability maps of pH, EC, SAR, RSC and quality of groundwater for Prakasam were developed for monitoring of irrigation groundwater quality of the district.

***Keywords*:** Prakasam ground water quality, EC, RSC, SAR, IWQI, Spatial variability

Agriculture is largely dependent on resources like soil and water. Water is very crucial for profitable crop production. Irrigation water quality affects the soil production by limiting the nutrient use efficiency of crop through salt buildup in the rhizosphere zone. In semi-arid and coastal regions due to limited or non-availability of good quality surface water increases the demand on poor quality groundwater as alternate source for irrigation (Gupta et al 2019). Groundwater plays a crucial role in agriculture for doubling of farmers income through intensification of crops on a unit land round the year. Good quality groundwater increases the crop production, sustains soil health and improves the nutrient use efficiency of crop. Farmers can accommodate more number crops and cropping systems along with suitable farming systems for sustaining farm income throughout the calendar year. In this context it is necessary to assess quality of groundwater in arid and semi -arid regions for irrigation. Keeping this in view a study was conducted to evaluate spatial variability and irrigation water quality of groundwater in Prakasam district of Andhra Pradesh.

MATERIAL AND METHODS

Study area: Prakasam district is located in Eastern coastal plain of hot sub humid to semiarid eco -region and lies in between 14°57' 00" and 16° 17' 00" of Northern latitudes and 78°43'00" and 80°25' 00"Eastern longitudes occupies central part of Andhra Pradesh. Prakasam has a total geographical area of 17,626 km^2. The district is bordered by Guntur district in North, east by Bay of Bengal with a coastal line of 102 km and on the South by Nellore and Kadapa districts, west by Kurnool district. Prakasam district has of 41163 tube wells and filter points and 22783 dug wells covering nearly 60 percent irrigated area of the district. Groundwater recharge for district is 142485 ha m. Total utilizable groundwater is 41499 ha m and present irrigation use is 8610 ha m. Groundwater development for district, considering all uses, is 29 percent. The major minerals of soil in weathered and fractured zone are granite, magnetite, quartz, silica sand, barytes, feldspars, slate stone, lime shell, laterite. Alluvial and colluvial materials are dominant in river plains and valley low lands. Shallow Red soils occupy 51%, deep black cotton soils in 41%, Sandy loam soils 6% and sandy soils 2% of the total area. Coastal line has fresh water in the areas around Chirala, Vetapalem, Chinnaganjam, Nagaluppalapadu, Kothapatnam, Ulavapadu and Tanguturu with thickness of 15.0 m due to presence sandy soils.

Analysis of groundwater: A total of 261 groundwater samples from different sources like bore wells and open wells collected. Around 5 to 6 samples were randomly collected from each mandal of Prakasam district with GPS coordinates (Fig. 1). Preconditioned clean high density polythene bottles were used for sampling, rinsed three times using sample prior to sample collection. The dug wells waters were lifted to the ground surface by rope and bucket while tube well waters

were pumped to the surface by using hand pump. The pumps were run for 5-6 minutes prior to collection of water samples. Samples were collected in polyethylene bottles and immediately toluene was added to avoid microbiological deterioration. Standard procedures were (Table 1) followed to analyze the quality of water. Sodium Adsorption Ratio (SAR), RSC were calculated by using the formulas given by Richards (1954) such as SAR = Na/ $((Ca^{2+}+Mg^{2+})/2)^{0.5}$ and RSC = $(CO_3^{2-} + H\,CO_3^-) - (Ca^{2+} + Mg^{2+})$. The Na^+, Ca^{2+} and $Mg2^+$ are in m e L^{-1}. RSC, CO_3^{2-}, $H\,CO_3^-$, Ca^{2+} and Mg^{2+} are in meq L^{-1}.The RSC, SAR, KR, SSP, PI was computed for irrigation water quality index (IWQI).

Kelley's ratio: Kelley's ratio was used to classify the irrigation water quality (Kelley 1940), which is the level of Na^+ measured against calcium and magnesium. The formula for calculating the Kelley's is as follows

$$KR = \frac{Na^+}{(Ca^{+2} + Mg^{+2})}$$

Where the concentration of ions is in mg/L

Soluble sodium percentage (SSP): Sodium concentration in groundwater is a very important parameter in determining the irrigation quality. The formula used for calculating the sodium percentage (Wilcox 1955)

$$Na\% = (Na^+ + K^+)/(Ca^{+2} + Mg^{+2} + K^+ + Na^+) \times 100$$

Where all ionic concentrations are in meq/L.

Permeability index: Long-term use of irrigation contains Na^+, Ca^{+2}, Mg^{+2} and HCO_3^- ions greatly influence the soil permeability. Doneen (1964) expressed the degree of soil permeability in terms of permeability index (PI).

$$PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Ca^{+2} + Mg^{+2} + Na^+)} \times 100$$

Where all ionic concentrations are in meq/L.

Statistical analysis and mapping: Research data were analyzed in SPSS 20.0 using Pearson correlation coefficient matrix to know significant variations between the physicochemical properties. Descriptive statistics were calculated using Microsoft Excel (Microsoft, WA, USA) spread sheet. Spatial distribution of groundwater quality was depicted in figures using Q-GIS 3.16.10.

RESULTS AND DISCUSSION

Spatial variability in pH of groundwater: The pH of water varied from 6.6 to 9.1(Table 2) with a mean of 7.6. The low pH may be due to presence of forest areas in certain pockets. Performance crops will be good at pH of groundwater is >6.5. Higher pH (>8.5) of ground water may be due to dominance of Na^+, Ca^{+2}, Mg^{+2} and CO_3^- and HCO_3^-ions and increases the clogging problems in emitters in pressurized irrigation system (Gupta et al 2019). The spatial variability of pH in groundwater in Prakasam (Fig. 2) indicate the suitability of groundwater for irrigation in majority of the district. Significant positive correlation observed between pH and CO_3^{-2} and RSC of groundwater. Vinothkanna et al (2020) with groundwater of Dindigul district and Naidu et al (2020) with Nellore district of Andhra Pradesh also expressed the same correlation with pH.

Spatial variability in electrical conductivity (EC) of groundwater: The EC values in water of various mandals of Prakasam district ranged from 0.5 to 31.0 dS m^{-1} with a mean

Table 1. Methods used for estimation of different hadrochemical parameters of groundwater

Parameters	Method used
pH	Glass electrode (Richards1954)
EC(Electrical conductivity)	Conductivity Bridge method (Richards1954)
Na^+ (Sodium)	Flame Photometric method (Osborn and Johns 1951)
K^+ (Potassium)	Flame Photometric method (Osborn and Johns 1951)
Ca^{+2}(Calcium)	EDTA titration method (Richards 1954)
Mg^{+2}(Magnesium)	EDTA titration method (Richards 1954)
CO_3^{-2}(Carbonate)	Acid titration method (Richards1954)
HCO_3^- (Bicarbonate)	Acid titration method (Richards1954)
Cl^- (Chloride)	Mohr's titration method (Richards1954)
SO_4^{-2} (Sulphate)	Turbidity method using $CaCl_2$ (Chesnin and Yien 1950)

Table 2. Range and average of quality parameters in groundwater of Prakasam district

Parameter	Range	Mean
pH	6.6-9.1	7.6
EC (dSm^{-1})	0.5-31.0	2.26
CO_3^{2-} (me L^{-1})	0.0-1.4	0.07
HCO_3^- (me L^{-1})	1.6-21.8	8.7
Cl^- (me L^{-1})	0.8-318	11.92
SO_4^{2-} (me L^{-1})	0.21-17.08	2.01
Ca^{2+} (me L^{-1})	0.8-48.0	4.93
Mg^{2+} (me L^{-1})	0.4-105	5.83
Na^+ (me L^{-1})	0.7-355	15.0
K^+ (me L^{-1})	0.004-30.04	0.69
RSC (me L^{-1})	-146-19.4	-1.98
SAR	0.42-40.6	7.40
KR	0.16-25.0	2.35
SSP	12.8-94.5	53.0
PI	27.3-119	68.8
IWQI	34-280	128

of 2.26 dS m^{-1} (Table 2, Fig. 3). Electrical conductivity is customarily used for indicating the total concentration of the ionized constituents of natural water.

The electrical conductivity classes (Table 3) were grouped into different classes up to 31 dSm^{-1}. Out of 261 samples collected 57.09 per cent samples had <2 dSm^{-1} followed by 30.65 per cent in range of 2-4 dSm^{-1} followed by 5.36 per cent in 4-6 dSm^{-1}, 2.30 per cent in 6-8 dSm^{-1} range, 2.68 per cent in 8-10 dSm^{-1} and 1.92 per cent in 10-31 dSm^{-1} range. The variation in EC may be due to variation in hydro-geological conditions and the anthropogenic activities of the region. Relationship between EC (dSm^{-1}) and total cations, total anions indicating that ionic constituents of groundwater samples exhibit positive correlation (Fig. 3a) with salinity of groundwater.

Concentration of cations: The cations viz., calcium, magnesium, sodium and potassium concentration in water samples varied from 0.8-48.0, 0.4-105, 0.7-355 and 0.004-30.04meq l^{-1} with mean values of 4.93, 5.83, 15.0 and 0.69 meq L^{-1} respectively. Concentration of cations followed the order sodium> magnesium >calcium >potassium. Dominance of Magnesium ion in groundwater indicates the mixing of seawater (Shalini and Bhardwaj 2017)

Concentration of anions: The anions viz., carbonate, bicarbonates, chloride and sulphate concentration varied from 0.0-1.4, 1.6-21.8, 0.8-318 and 0.21-17.08 meq L^{-1} with an average of 0.07, 8.70, 11.92 and 2.01 meq L^{-1}, respectively. The abundance of ions for most of the water samples are HCO_3^->Cl^-> SO_4^{-2}> CO_3^{-2}. The bicarbonate and chloride ions are dominant among all the anions then followed by sulphates and carbonates.

Spatial variability in sodium adsorption ratio (SAR): The SAR of Prakasam district groundwater ranged from 0.42-40.6 (m mol $l^{-1})^{1/2}$ with a mean of 6.27 (m mol $l^{-1})^{1/2}$. The lowest SAR of 0.42 (m mol $l^{-1})^{1/2}$ in water samples was observed in Voletivaripalem mandal and the maximum value of SAR was found as 40.6 (m mol $l^{-1})^{1/2}$ in Ongole mandal. Crop productivity will be adversely affected by continuous use of high SAR water due to decrease in soil infiltration rate (Gupta 2015). The spatial variability of SAR of groundwater in Prakasam district**,** indicated that the 4.22 % samples under high to very high hazard of Na^+ and are unsuitable for irrigation (Fig. 4 and Table 4).

Spatial variability in Residual Sodium Carbonate (RSC): The residual sodium carbonate (RSC) of groundwater in Prakasam district varied from -146-19.4 meq L^{-1} with a mean of -1.98meq L^{-1}. The highest RSC of 19.4 meq L^{-1} in water samples was in parts of Voletivaripalem mandal. The spatial distribution of RSC in groundwater was depicted in Figure 5 and observed that 75.48 % samples **(**Table 5) were of safe category, 9.96 % moderately suitable for irrigation and 14.56 % unsuitable for irrigation purposes, prolonged use of high RSC water may cause development of sodic soils due to a tendency of calcium to precipitate as carbonates (Subbaiah et al 2020).

Ionic correlation studies: The order of dominance is Na^+> Mg^{+2}>Ca^{+2}> K^+ for cations and HCO_3^->Cl^->SO_4^{-2}> CO_3^- for anions. Therefore, the chemical nature of the groundwater was characterized by Na^+- Mg^{+2}-HCO_3^--Cl^-water type. Highly significant correlation was observed between major cations and anions, Na^+ - Ca^{+2} (and Na^+ - Mg^{+2}, Na^+ - Cl^- (r = and Na^+ - HCO_3^- and significant positive correlation between $Mg^{+2}$and Ca^{+2} (Mg^{+2} and Cl^-), and between Ca^{+2} and Cl^-(Table 6).

The Kelly's ratio was highly significantly positively correlated with pH, EC and Na^+ at 1% level of significance. The RSC of groundwater had high positive correlation with pH, CO_3^{-2}, HCO_3^- and negative with Ca^{+2} and Mg^{+2}. Indicates that continuous use of irrigation water with high RSC (>2.5 meq L^{-1}) increases the exchangeable sodium percentage and pH of soil and adversely affects the infiltration rate of the soil (Gupta et al 2019). The PI has significantly positive with pH and bicarbonates.

Classification of ground water quality for irrigation purpose: The groundwater of Prakasam district was classified into seven classes for irrigation purpose (Minhas and Gupta 1992). The 37.16 % were of good quality, 27.20 % were of marginally saline, 2.29 % of saline, 8.81% high SAR saline, 9.19 % of marginally alkali, 6.89 % of alkali and 8.42% of highly alkali (Table 7). Spatial variability in irrigation water quality of groundwater (Fig. 6). The quality of groundwater influenced by various factors like topography, lithology, geological structure, depth of weathering, extent of fractures, drainage pattern, climate conditions (CGWB, 2019). Kelley's ratio for all the groundwater samples is calculated and it lies between 0.15 to 33.04 mg/L. Kelley's ratio value (Table 8) less than one is suitable for irrigation (28.35 %) and more than one is unsuitable (71.65 % samples). Soluble sodium percentage (SSP) value <50 indicates (Table 9) good for irrigation (40.23 %) and >50 indicates not good for irrigation (59.77 %). Permeability index (PI) value indicates 37.55 per cent samples suitable for irrigation and 62.45 per cent samples marginally suitable for irrigation (Table 10). The higher concentration of bicarbonate ions in groundwater reacts with Ca and precipitate as $CaCO_3$ and reduces the permeability of soil (Gupta et al 2019).

Irrigation water quality index (IWQI) was computed by using water quality indices viz., SAR, RSC, KR, SSP and PI. The indices values were summed and then classified into excellent to unfit groundwater quality (Table 11). The 64.75% of groundwater was found poor in quality and slightly

Table 3. Ground water quality based on electrical conductivity (dSm^{-1})

EC (dSm^{-1})	No. of samples	Per cent of samples
0-2	149	57.09
2-4	80	30.65
4-6	14	5.36
6-8	6	2.30
8-10	7	2.68
10-31	5	1.92

Table 4. Classification of ground water based on SAR

SAR	No. of samples	Per cent of samples
<10	214	81.99
10-18	36	13.79
18-26	6	2.30
>26	5	1.92

Table 5. Classification of ground water based on RSC (mel^{-1})

Residual sodium carbonate (mel^{-1})		No. of samples	Per cent of samples
Class	Value		
None	<2.5	197	75.48
Slight to moderate	2.5-4.0	26	9.96
Severe	>4.0	38	14.56

Table 8. Classification of groundwater for irrigation based on Kelly's ratio (Kelly 1940)

Kelly's ratio	Suitability	Sample	
		Numbers	Per cent
<1.0	Good	74	28.35
>1.0	Not good	187	71.65

Table 6. Correlation matrix among the chemical constituents of the groundwater

	pH	EC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	CO_3^{-2}	SO_4^{-2}	RSC	SAR	KR	SSP	PI
pH	1														
EC	-0.111	1.000													
Ca^{+2}	-0.375	0.771**	1.000												
Mg^{+2}	-0.161	0.902**	0.817**	1.000											
Na^{+}	-0.027	0.944**	0.688**	0.885**	1.000										
K^{+}	-0.112	0.286**	0.275**	0.220**	0.101	1.000									
Cl^{-}	-0.125	0.931**	0.814**	0.948**	0.946**	0.178	1.000								
HCO_3^{-}	0.105	0.287**	-0.052	0.121	0.236**	0.238	0.121	1.000							
CO_3^{-2}	0.367**	-0.004	-0.133	-0.046	0.026	-0.057	-0.051	0.142	1.000						
SO_4^{-2}	-0.012	0.102	-0.105	-0.086	-0.077	-0.094	-0.097	-0.042	0.004	1.000					
RSC	0.277**	-0.792	-0.916**	-0.920**	-0.764	-0.179	-0.885	0.221	0.136	0.083	1.000				
SAR	0.223	0.716	0.245	0.449	0.754**	0.049	0.586	0.531	0.169	-0.044	-0.233	1.000			
KR	0.418**	0.217**	-0.195	-0.031	0.289**	-0.047	0.109	0.519**	0.264**	0.017	0.240**	0.798**	1.000		
SSP	0.297**	0.303**	-0.154	0.034	0.356**	0.083	0.204	0.561**	0.113	0.011	0.193	0.750	0.744	1.000	
PI	0.406**	0.027	-0.410	-0.183	0.161	-0.097	-0.011	0.437**	0.146	0.069	0.395**	0.556**	0.689	0.898	1.000

Note: RSC= Residual Sodium Carbonate ; SAR= Sodium Adsorption Ratio; KR = Kelly's Ratio; SSP= Soluble sodium percentage; PI= Permeability index
* Significant at 0.05 Probability level, **Significant at 0.01 probability

Table 7. Classification of Groundwater for irrigation (Minhas and Gupta 1992)

Rating	EC (dSm^{-1})	SAR	RSC (me L^{-1})	Number of samples	Per cent samples
A. Good	<2	<10	<2.5	97	37.16
B. Saline					
Marginally saline	2-4	<10	<2.5	71	27.20
Saline	>4	<10	<2.5	6	2.29
High SAR saline	>4	>10	<2.5	23	8.81
C. Alkali water					
Marginally alkaline	<4	<10	2.5-4.0	24	9.19
Alkali	<4	<10	>4.0	18	6.89
Highly alkaline	variable	>10	>4.0	22	8.42

Table 9. Classification of groundwater based SSP for irrigation (Richards 1954)

Kelly's ratio	Suitability	Sample	
		Numbers	Per cent
<50	Good	105	40.23
>50	Not good	156	59.77

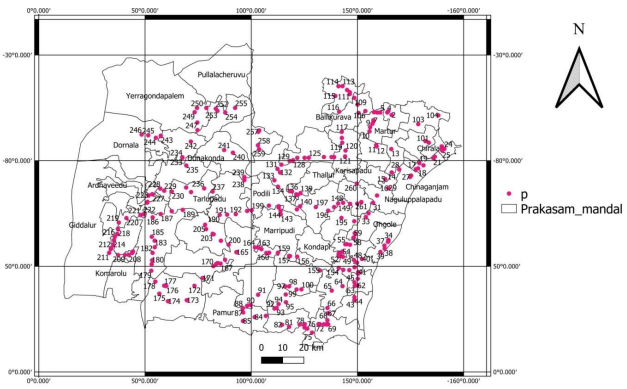

Fig. 1. Ground water sampling points in Prakasam district

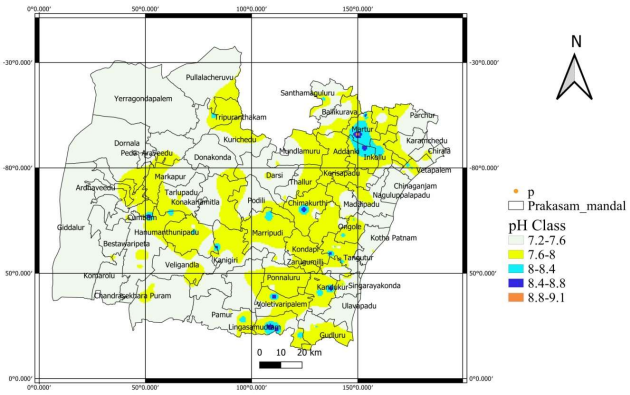

Fig. 2. Spatial distribution of pH in groundwater of Prakasam district

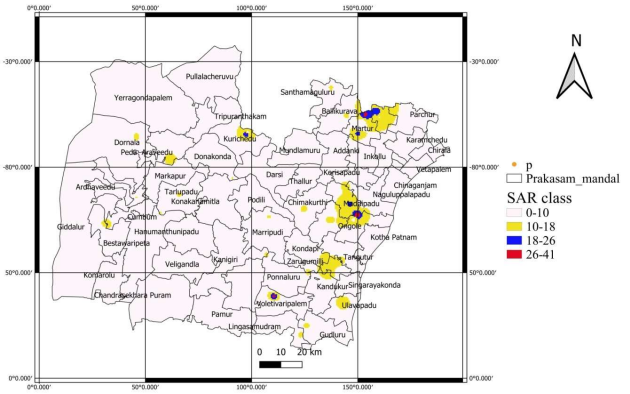

Fig. 4. Spatial distribution of SAR in groundwater of Prakasam district

Table 10. Classification of groundwater based on permeability index (PI) for irrigation (Doneen1964)

Classification of PI	Permeability	Suitability	Sample	
			Number	Per cent
I	>75	Suitable	98	37.55
II	25-75	Marginal	163	62.45
III	<25	Unsuitable	0	0.0

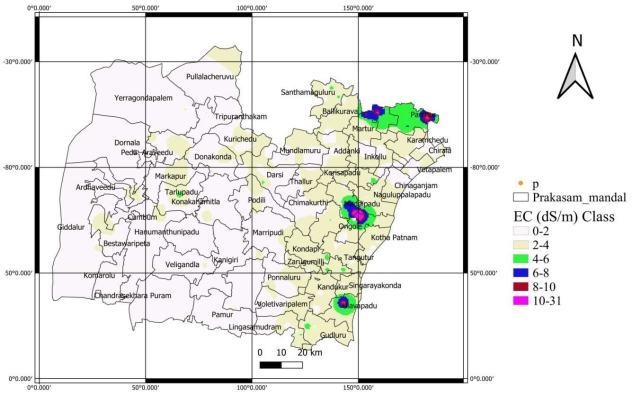

Fig. 3. Spatial distribution of EC (dS/m) in ground water of Prakasam district

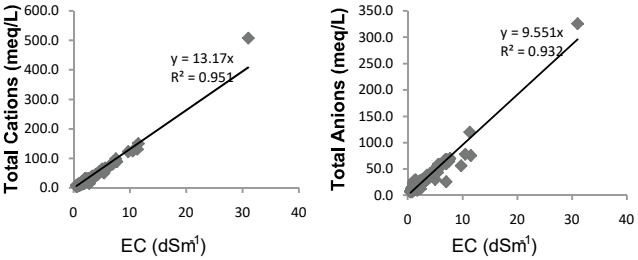

Fig. 3a. Relationship between EC and ionic constituents of groundwater

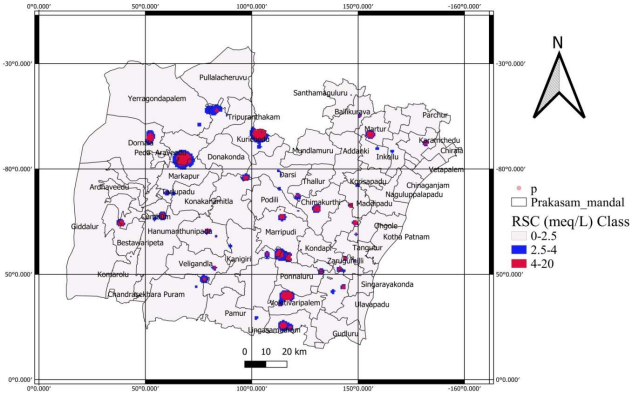

Fig. 5. Spatial distribution of RSC (meq/l) in groundwater of Prakasam district

Table 11. Classification of groundwater based on IWQI for irrigation

Water value range	Water quality	No. of samples	Per cent samples	Sustainable state
<50	Excellent	8	3.07	Sustainable
51-100	Good	66	25.29	Sustainable
101-200	Poor	169	64.75	Slightly unsustainable
201-300	Very poor	18	6.90	Unsustainable
>301	Very bad	8	3.07	Highly unsustainable

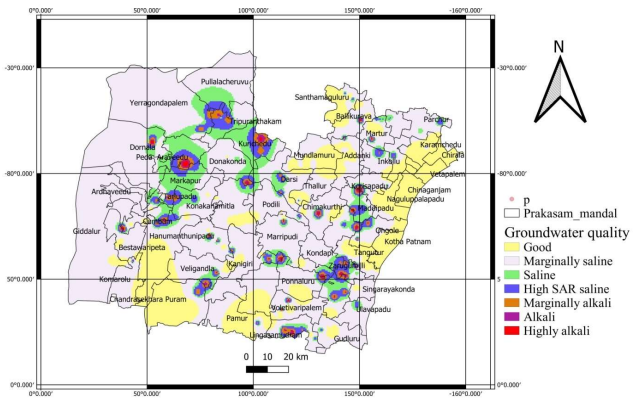

Fig. 6. Spatial distribution of groundwater quality in Prakasam district

unsustainable for irrigation, 6.9% was found very poor and unsustainable in quality, 3.07% was very bad and highly unsustainable, only about 3.07 % in excellent quality and 25.29% in good quality for irrigation. The results were in conformity with Kumar and Kumar (2021).

CONCLUSIONS

The groundwater quality in Prakasam district differed from place to place. The dominance of major ion was in the order ofNa^+> Mg^{+2}>Ca^{+2}> K^+ for cations andHCO_3^-> Cl^-> SO_4^{-2}> CO_3^- for anions, which indicated the quality of irrigated groundwater is Na^+- Mg^{+2}-HCO_3^--Cl^-type. The spatial maps of different parameters, prepared using GIS could be valuable for policy makers for initiating groundwater quality monitoring of the area as well as for suggesting management plans for the farmers in selection of suitable crops and other agronomic management practices for getting profitable yields without affecting the soil health. The results showed that 64.75% groundwater of Prakasam district were found poor in the quality and slightly unsustainable for prolonged use. About 6.9 % samples very poor and unsustainable, 3.07 % samples are very bad in quality highly unsustainable for irrigation. About 8% samples are excellent and 25.29 % samples are good and sustainable to use for irrigation.

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Microhabitat of Indian Rock Pythons (*Python molurus*) in Moyar River Valley, Tropical India

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***Abstract*:** The knowledge of microhabitats used by a species is essential for its effective conservation and management. This study aimed to quantify the microhabitat use of Indian rock pythons (*Python molurus*) in the Sathyamangalam and Mudumalai Tiger Reserves (STR & MTR), Tamil Nadu. Fourteen pythons were captured through intensive search and opportunistic methods from STR, MTR, and nearby villages and then radio-track between 2018 and 2020. The various microhabitats were categorized and quantified based on sightings of the radio-tagged pythons. A total of 401 microhabitat locations were collected and classified into eight categories: burrows, dead fallen trees, dry bushes, green bushes, trees, open areas, rock crevices, and water. The study results showed that the microhabitat use of male and female pythons was significantly related . The number of sightings was converted into proportions, revealing that dry and green bushes were the most preferred microhabitats by pythons. This study provides valuable insights into the microhabitat preferences of *P. molurus* in tropical climatic conditions and can help in the formulation of effective policies and measures to protect this species and its micro- habitats.

***Keywords*:** Indian Rock Pythons, *Python molurus*, Bushes, Microhabitat, Radio-transmitter, Moyar river valley

Snakes are known to inhabit diverse habitats and microhabitats, which include terrestrial, aquatic, and arboreal. Microhabitats differ from place to place, including stone, burrows, paddy fields, streams, rock, leaf litter, open forests, forest edges, and water bodies (Lalremsanga et al 2011, Rahman et al 2014). Among pythons, different species have an affinity over various landscapes, habitats, and microhabitats. Indian rock pythons (*Python molurus*) are known to inhabit a wide range of habitats across their distribution range. *P. molurus* occupy scrub jungles, moist forests, evergreen forests, grasslands, and mangrove ecosystems and are water dwellers; thus, they prefer zones with water bodies like swamps and riparian habitats (Sharma 2003, Whitaker and Captain 2004). Pythons also thrive in rocky hills (Hunter et al 2018, Babar et al 2019).

The microhabitat selection in *P. molurus* is also diverse. They are known to use burrows, tree hollows, marshes, wet rocky ledges along the pools and streams, thickets found in the mangrove, bushes, dense vegetation clumps, large rotten logs, treetops, water reeds, and leaf litters, caves, crevices, and ruins (Sharma 2003, Whitaker and Captain 2004, Mukherjee et al 2017, Babar et al 2019). However, the microhabitat usage of *P. molurus* in the tropical climate regions have not been studied yet. Burmese pythons (*Python bivittatus*) are the sister species of *P. molurus*; in general, they are known from South East Asia, inhabiting forests, lowlands of the tropics, grasslands, agricultural lands, and aquatic habitats (Barker and Barker 2008, Cota 2010, Stuart et al 2012, Rahman et al 2014). Walters et al (2016) found the *P. bivittatus* to show a negative selection over freshwater bodies but preferred canopy-associated coniferous forests. However, most of the studies show *P. bivittatus* to have a positive selection towards water or aquatic habitats irrespective of the native population or invasiveness in a different geographical area (Cota 2010, Stuart et al 2010, Rahman et al 2014, Hunter et al 2015, Mustascio et al 2017, Conyers and Roy 2021, Smith et al 2021). Therefore, habitat selection is an essential cue in the pythons, and various ecological and climatic factors influence it.

P. molurus is a Schedule I animal of the Indian Wildlife Protection Act 1972. The International Union for Conservation of Nature assessment lists them in the Near Threatened category (Aengals et al 2021). The species was facing population decline due to severe habitat loss and poaching (Babar et al 2019). In this context, understanding the microhabitat use of this species in the tropical climate will support their conservation management from habitat degradation. In this study, quantified the proportion of microhabitat use in the *P. molurus* in the tropical climatic region, Southern India. The study results would help in identifying and conserving natural microhabitats of the study site which can also be supported in identifying suitable translocation sites for rescued individuals from conflict zones.

MATERIAL AND METHODS

Study area: The study was conducted between 2018 and

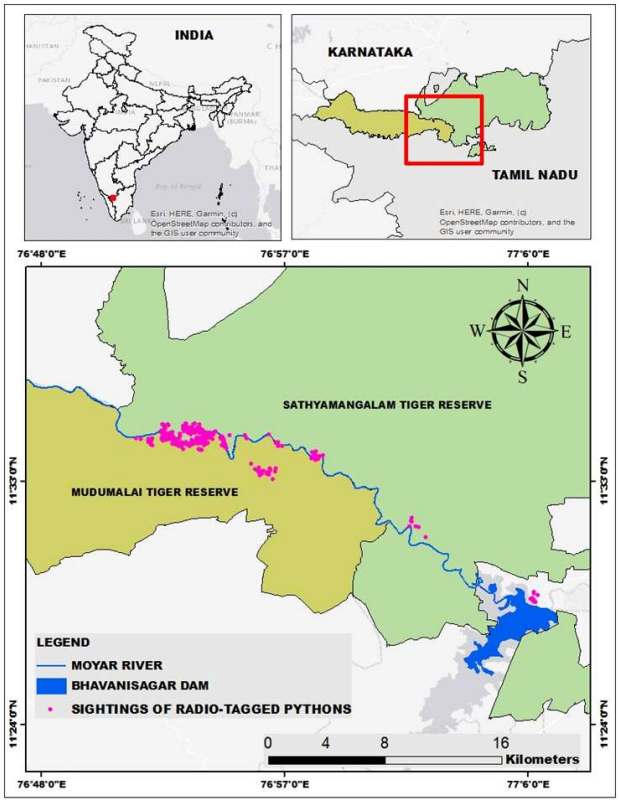

Fig. 1. Study area map

2020 in the Moyar River Valley (MRV), a tropical climate region of India, which lies in both the STR and MTR (Fig. 1). The major forest types of the region are Southern tropical dry thorn forest, Southern tropical dry deciduous forest, Southern tropical moist deciduous forest, Southern tropical semi-evergreen forest, moist bamboo brakes, and Riparian forests. Through the intensive search, opportunistically captured 14 pythons from the MTR, STR, and adjacent villages. The pythons were radio-tagged, released in the study sites, and observed their microhabitat use.

Microhabitat classification: The study area was classified into eight broad microhabitat types (Fig. 2): 1. burrows; 2. dried fallen trees; 3. dry bushes (dried bushes dominated by invasive plant *prosopis sps*, debris and sticks, and leaf litter); 4. green bushes (including *prosopis* saplings); 5. trees (including tree hollows and tree roots); 6. open area; 7. rocky area (including rocky crevices and beneath the rocks); 8. water.

Surgical method for radio-tagging: The three types of VHF implantable Radio-transmitters, AI-2 Holohil with 17 g and 28 g sizes, and the ATS ARChive ARC400 tag of 14g was used. The transmitters were implanted into the coelomic cavity of individuals after the isoflurane gaseous anaesthesia (Renurt and Cundall 1984, Vishnu et al 2023). Simultaneously, we

A. Burrow; B. Dry Fallen Tree; C. Dry Bush; D. Green Bush; E. Tree; F. Open Area; G. Rocky Area/ Rocky Crevices; H. Water

Fig. 2. Types of Microhabitats

have collected morphometry details of individuals. In addition, we confirmed that the mass of each transmitter did not exceed 0.26 % body mass of the individuals. The individuals were given post-surgery care at the veterinary unit of the Sathaymangalam Tiger Reserve prior to release.

Data analysis: The radio-tagged pythons were tracked on different days in 2018-2020, and noted the microhabitat of each python and calculated the proportion of sightings in each microhabitat. The male and female microhabitat association was tested by using the chi-square test.

RESULTS AND DISCUSSION

Morphometry: Information on microhabitat use and movement patterns were obtained from 14 adult pythons, which were radio-tracked between 2018 and 2020 for a mean tracking day period of 444 days, and 29 data points were obtained per individual. These included six females (SVL 197.5-376 cm, mass 6.65kg to 36.25 kg) and eight males (SVL 172-252 cm, mass 3.3 kg-36.25kg).

Relationship of pythons with microhabitats: The null hypothesis of the study was that there would be no significant relationship between the microhabitat use of male and female pythons. However, the alternative hypothesis was supported by the results, which showed that the microhabitat use of male and female pythons was significantly related (x^2= 29.40, v=7, P <0.001) (Table 1 and Table 2). Pythons exhibit a pattern of microhabitat selection, with a preference for dry and green bushes and a tendency to avoid burrows.

Proportionality in microhabitat use: Female pythons utilized 49% of their microhabitats as green bushes, while male pythons only used 30% of their microhabitats for this purpose (Fig. 3, 4). In contrast, male pythons used green and dry bushes in equal proportions (30%), and female pythons were observed to use dry bushes at a rate of 22%. Most pythons were observed in dry bushes and green bushes during the study. Male pythons were seen the least inside water bodies (1%), while females were observed in water 7% of the time. Burrows was the least used microhabitat for female pythons (1%), while males were sighted in burrows at a proportion of 2%. The male pythons used rocky areas or rock crevices more often than females (12% compared to 6%) and were sighted in open areas more frequently than females, with a proportion of 10% compared to 5%. On the other hand, male pythons were found in treetops and tree hollows at a proportion of 8%, while female pythons were 6%. Dead fallen trees were used as microhabitats by males at a ratio of 7%, compared to only 4% for females. However, both males and females were observed in burrows at a minor proportion, with males at 2% and females at 1%.

Similar study on *P. bivittatus* conducted in Bangladesh reported that the pythons exhibited a strong preference for microhabitats such as bushes and thickets. In contrast, the major habitat type observed was bushy habitat or degraded forest, while the least observed habitats were paddy fields and trees (Rahman et al 2014). Dry bushes are the hiding sites for pythons, where they can be highly camouflaged and await prey and can be helpful to avoid predation. The moist substrate along the dry bushes is an essential microhabitat

Table 1. Frequency of microhabitat use by radio-tracked Indian Rock Pythons

	Burrows	Dead fallen trees	Dry bushes	Green bushes	Open areas	Trees	Rock crevices	Water	Total
Male	5	15	64	66	18	21	26	2	217
Female	1	8	40	90	11	10	12	12	184
Total	6	23	104	156	29	31	38	14	401
Total %	1.45	5.73	25.93	38.90	7.23	7.73	9.48	3.49	100

Table 2. Observed and expected frequencies

	Burrows	dead fallen trees	Dry bushes	Green bushes	Open areas	Trees	Rock crevices	Water	Grand total
Observed frequencies									
Male	5	15	64	66	18	21	26	2	217
Female	1	8	40	90	11	10	12	12	184
Total	6	23	104	156	29	31	38	14	401
Expected frequencies									
Male	3.24688	12.4464	56.2793	84.419	15.6933	16.7755611	20.5636	7.57606	217
Female	2.75312	10.5536	47.7207	71.581	13.3067	14.2244389	17.4364	6.42394	184
Total	6	23	104	156	29	31	38	14	401

for *Phrynonax poecilonotus* from another tropical country Brazil (dos Santos-Costa et al 2015). Studies conducted in the Keoladeo National Park have shown that *P. molurus* typically prefer burrows as microhabitats, particularly those located under *Salvadora* bushes (Ramesh 2012). Burrows are engineered shelters that provide crucial refuge and protection against temperature extremes, fire, and predation (Mukherjee et al 2017, Ramesh and Kamalakannan 2018).

Pythons have a strong affinity for water and prefer to reside in it. *P. molurus*, is a good swimmer and can remain submerged in water for at least 30 minutes if necessary (Sharma 2003). Similarly, most studies of *P. bivittatus* show that this species has a positive selection towards water or aquatic habitats (Barker and Barker 2008, Cota 2010, Stuart et al 2010, Rahman et al 2014, Hunter et al 2015, Mustascio et al 2017, Conyers and Roy 2021, Smith et al 2021). These observations suggest that water plays a critical role in the behaviour and biology of pythons. Rocky areas, trees, and dried fallen trees are the other microhabitats used by the *P. molurus* in the MRV. The *P. molurus* prefer the microhabitats like rock crevices, tree hollows, and rock bottoms during hibernation in northern India between late December and to the middle of February (Sharma 2003). They are also skilled climbers and can suspend themselves from tree branches, remaining motionless as they wait for prey to come within reach (Sharma 2003). Similarly, open areas can be beneficial for maintaining thermoregulation in pythons. A study on *Hyperolius viridiflavus* found that thermal specialization for hot temperatures was associated with the microhabitat selection of open areas (Lelièvre et al 2011). All of the microhabitat types described are crucial for fulfilling the ecological requirements of this species in the study area.

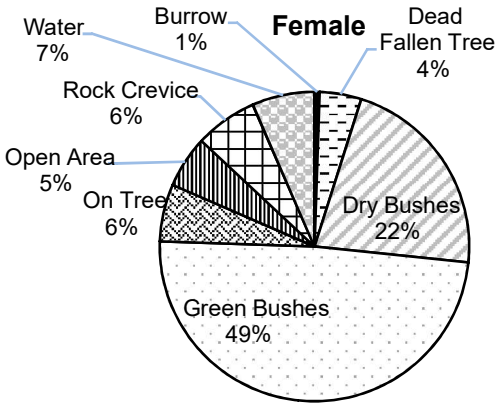

Fig. 3. Proportion of female microhabitats

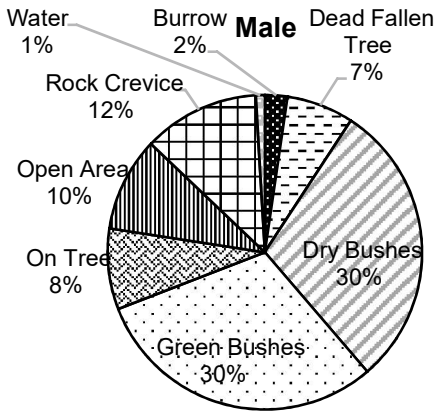

Fig. 4. Proportion of male microhabitats

CONCLUSIONS

There is a significant relationship between sex and microhabitat selection in pythons. The proportion of microhabitat use was found to be varied according to microhabitat types. *P. molurus* in tropical regions, where they tend to prefer bushes, as they have been known to prefer burrow microhabitats in sub-tropical regions. Knowledge of the exact microhabitats used by *P. molurus* is essential for effective conservation and management in the context of habitat fragmentation and changing climatic conditions. All of the microhabitat types described are crucial for fulfilling the ecological needs of this species in the study area. However, these microhabitats are often overlooked in many conservation plans. It is essential to include them in conservation and management practices to ensure the well-being of this species. The long-term studies on microhabitat selection in pythons will provide more precise results and information on seasonal shifts in their microhabitat use.

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Status, Characteristics and Factors Affecting Roadkills on NH-64: The Dandi Path, Navsari, Gujarat, India

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Abstract: Roads are among the significant threats to the conservation of wild mammals across the globe. In the present study, we assess roadkill, its characteristics, and factors affecting their presence on a stretch of NH-64 of Navsari district. To evaluate roadkills, we monitored the road weekly; whereas to assess the factors affecting road presence, we followed used-unused sampling. A total of 70 roadkills were encountered from a sampling effort of 336 kilometres from October 2021 to March 2022. Reptiles were the most affected taxonomic groups, followed by amphibians and mammals. Among reptiles, the garden lizard was the most killed species, while the common frog and five stripped squirrel were the most killed among amphibians and mammals. Maximum kills happened during March, while maximum kills happened in the agricultural habitat. Shrub cover, ground cover, distance from the road edge, and distance from human habitation affected roadkill positively, while canopy cover was related negatively. The present study will act as a baseline for the future, and help fill the knowledge gap in roadkill studies in a human-dominated landscape.

Keywords: Roadkill, Linear infrastructure, Development, Reptiles, Amphibians, Mammals, Conservation

The increase in human population has led to increased demands for better facilities, leading to a rapid increase in global developmental activities (Steffan et al 2015). Such developmental activities have proven detrimental to wildlife across the globe since they have led to habitat destruction, fragmentation, and high access to natural resources, leading to a decline in wildlife population and illegal extraction of natural resources, respectively (Bastin et al 2019). Development of the road network is affecting wildlife negatively (Strano et al 2017). Modern civilizations also used to develop across the roads for easy human mobility and move goods among locations, further increasing the negative effects on wildlife (Laurance et al 2009). Roads affect wildlife in direct and indirect ways. Direct effects involve deaths through vehicular traffic. For example, Lalo (1987) estimated vertebrate mortality on roads in the United States at 1 million individuals per day. Road construction and widening lead to habitat destruction and fragmentation and severely impact species that used to avoid the road edge (Lesbarreres and Fahrig 2012). Roads also restrict the movement of the species, known as the barrier effect, and divide areas in the temporary island, especially during high vehicular activity (Shepard et al 2008, Kociolek et al 2011). The barrier effect also reduces the gene flow, which negatively affect the species' population size (Riley et al 2006). Also, road construction changes the environment along the roads by changing the soil properties, hydrological cycles, and increasing noise and light intensity (Laurance et al 2009). The adverse effects of roads are so deep that it has emerged in a new ecological discipline known as "Road Ecology" (Forman 1998).

India has the second largest human population globally, and during the last few years, its economy has grown very fast. A highly growing economy has led to increased infrastructure development, including roads. For example, in India, highway length (national and state highways) increased by 50% between 1980-2000. At the same time, road length increased by nearly 40% between 2001 and 2015 (https://data.gov.in/). Nayak et al (2020) found that 46,700 kilometres of roads exist in India's forest area, which has resulted in forest fragmentation and habitat loss across the country. Most of India's studies on road ecology have been concentrated on the stretches of roads going through the protected area or landscape surrounding protected areas. However, there is a paucity of studies in human-dominated landscapes regarding roadkill, which limit understanding of road impact on wildlife in the human-dominated landscape.

In the present study, we aimed to fill the knowledge gap of road ecology by assessing the status and factors affecting roadkills on a stretch of 14 kilometres on National Highway 64 in the human-dominated landscape of Navsari district, Gujarat, India. Objectives of the present study were a) To assess the status and characteristics of roadkills b) To assess factors affecting the presence of roadkill

MATERIAL AND METHODS

Study area: The study area of the present study includes National Heritage Highway 64 between Eru char Rasta to Dandi Sea Coast (Fig. 1). Dandi is a village in the Jalalpore taluka in Navsari District of Gujarat state of India. Dandi is located on the coast of the Arabian Sea near the city of Navsari between 20.95 0 N -72.93 0 E. This is one of the busiest routes of the area and used commonly by two-wheelers and cars. The Dandi road consisting habitats of mostly rainfed crop lands, barren lands, human habitations, pond and a few coastal forest patches. The entire road passes through villages Ethan, Pethan, Kothmadi, Matvad and Samapor. The vegetation present on either side of the road consists of the plant species namely *Ficus benghalensis* L., *Ficus religiosa* L., *Azadirachta indica* A. Juss., *Eucalyptus globules* Labill., *Albizia lebbeck* (L.) (Personal Observation).

Kill monitoring: Sampling was carried out from October 2021 to April 2022 on the road from Eru Char Rasta to Dandi Sea Coast, covering a distance of 14 km (Fig. 1). The road was surveyed weekly from 6 AM to 10 AM using a bicycle. To avoid the problem of duplication of kills, we first monitored five kills of different species, such as amphibians, small mammals, and reptiles. We found that kills decayed entirely in one week. Therefore, we monitored kills every week, assuming that during this time interval, identified kills would be decayed totally, and hence duplication of kills could be avoided. While sampling, going towards Dandi, one side of the road was sampled, and another side was sampled while coming back. Data recorded while encountering roadkill include species names, dates, and broad habitat types. Broad habitat types include agricultural land, human habitation, orchards, wetland, and pond. Field guide and taxonomic keys were used for the species identification (Daniel 2002, Menon 2014).

Factors affecting kill sites: To assess site-specific factors affecting roadkills, we followed a used-unused sampling design where each kill was treated as a used location, and a random location was treated as an unused location (Boyce et al 2002). We considered five variables: canopy cover, shrub cover, ground cover, distance from the road edge, and distance from human habitation. Canopy cover, shrub cover, and ground cover were quantified on a 0- 100 scale by laying down a kill cantered plot of a 20 m radius (Chaudhary et al 2020). The distance of the kill from the road edge was quantified using a measuring tape, while the distance of the kill from human habitation was quantified by measuring the distance of the nearest house using a laser range finder. Further similar variables were collected at a random location on roads and considered as absence points of kills.

Analysis: We segregated roadkills frequency concerning species, taxonomic groups, broad habitat types, and months. Since our data consist of frequency therefore, we used the chi-square test of homogeneity (Zar 2006) to examine a) if the frequency of roadkill is distributed proportionally among different species or taxonomic groups and b) if the frequency of roadkill is distributed proportionally in different habitat types and months.

To assess the factors affecting the presence of kill sites, we used Generalized Linear Models (GLM) (Guisan et al 2002). Since data collection was based on a used-unused sampling design, therefore we used binomial distribution with a logit link (Guisan et al 2002). The presence and absence of kills were used as response variables, while variables defined earlier section were used as predictor variables. A list of all possible models was created using the dredge function of package MuMIn in program R, and a model with $\Delta AIC<2$ was considered the final model (Burnham and Anderson 2002). To assess the relative importance of the model, we used ΔAIC and AIC weight (Burnham and Anderson 2002). Model averaging was done for the models with $\Delta AIC<2$ following Burnham and Anderson (2002). Best model accuracy was assessed through the model validation using sensitivity analysis which is best suited for the binomial outcomes. In validation analysis, 80% of the data was used as a training data set, while 20% was used as testing data set. All analysis was carried out in R statistical software (R Core Team 2018).

RESULTS AND DISCUSSION

A total of 336 kilometres of roads were monitored during the survey, resulting in roadkill of 70 individuals of 15 species, all of which were under the least concern category (Table 1). Out of 70, the maximum number of individuals belongs to reptiles (27), followed by amphibians (23) and mammals (20) (χ 2 = 1.04, df = 2, $p<0.05$). The overall kill rate (Individual killed per kilometre) during the study period was 0.48. The highest kill rate was observed for reptiles, i.e., 0.08, followed by amphibians, i.e., 0.06, and mammals, i.e., 0.05.

The maximum number of kills found during the month of March (24), followed by February (14), April (13), October (9), December (5), November (3), January (2) ($\chi 2$ =36, df = 6, $p<0.05$) (Fig. 2). Maximum roadkills were found in the agriculture land (28), followed by human habitation (16), orchard (16), wetland (8) and pond (2) ($\chi 2$ = 27.41, df = 4, $p<0.05$) (Fig. 3).

Among reptiles, the highest number of kills were of common Garden lizard (*Calotes versicolor*) (15), followed by checkered keelback snake (*Xenochrophis piscator*) (4), rat snake (*Ptyas mucosa*) (4), common kukri snake (*Oligodon arnensis*) (1), Indian cobra (*Naja naja*) (1), wolf snake-

Lycodon (1) and green vine snake (*Ahaetulla nasuta*), (1) ($\chi 2$ =40.70, df = 6, p<0.05) (Table 1).

Among amphibians' the highest number of kills was of the Common frog (*Rana temporaria*) (11), followed by the Common Indian toad (*Duttaphrynus melanostictus*) (7), Unidentified species, and Indian skittering frog (*Euphlycti scyanophlyctis*) (1) ($\chi 2$ = 9.48, df = 3, p<0.05) (Table 1). Among mammals' the highest number of roadkill was of five striped squirrel (*Funambulus pennantii*) (8), followed by common tree shrew (*Tupaia glis*) (6), Indian Gerbil (*Tatera indiaca*) (4) and house rat (*Rattus rattus*) (2) ($\chi 2$ =4, df = 3, p< 0.05) (Table 1).

A total of eight models performed best (ΔAIC<2) and consisted of all habitat variables, i.e., canopy cover, shrub cover, ground cover, distance from the road edge, and distance from human habitat (Table 2). Model averaging found that shrub cover (b=0.14± 0.95), ground cover (b= 0.58±0.86), distance from road edge (b=1.62±1.11), distance from human habitation (b= 0.51±0.42) were positively associated with kill sites, while canopy cover (b= -1.23±1.16) was negatively associated with the kill sites (Table 2). Model validation analysis found an accuracy of 88 % and sensitivity of 89 %, which depicts the high accuracy of the best model used to evaluate the factor affecting kill sites.

Roadkill is among the most threatening human activities that could severely affect wildlife. Present study results show

Table 1. Road kill incidents of reptile, amphibian and mammal species reported and their IUCN status

Class	Comman name	Scientific name	IUCN status	Number of Individuals killed
Reptiles	Common garden lizard	*Calotes versicolor*	Least concern	15
	Checkered keelback snake	*Xenochrophis piscator*	Least concern	4
	Green vine snake	*Ahaetulla nasuta*	Least concern	1
	Indian cobra	*Naja naja*	Least concern	1
	Common kukri snake	*Oligodon arnensis*	Least concern	1
	Rat snake	*Ptyas mucosa*	Least concern	4
	Wolf snake	*Lycodon aulicus*	Least concern	1
Amphibians	Common frog	*Rana temporaria*	Least concern	11
	Common Indian toad	*Duttaphrynus melanostictus*	Least concern	7
	Unidentified	Unidentified	Unidentified	4
	Indian skittering frog	*Euphlyctis cyanophlyctis*	Least concern	1
Mammals	Five striped squirrel	*Funambulus pennantii*	Least concern	8
	Common tree shrew	*Tupaia glis*	Least concern	6
	Indian gerbil	*Tatera indica*	Least concern	4
	House rat	*Rattus rattus*	Least concern	2

Table 2. Factors affecting kill sites during the present study. (Only parameters for the best set of models with ΔAICc < 2 are reported)

Int	DFRE±S.E.	DFHH±S.E.	CC±S.E.	SC±S.E.	GC±S.E.	*df*	ΔAICc	MW
0.65	1.62±1.11	-	-	-	-	2	0.00	0.17
0.95	-	0.51±0.42	-	-		2	0.99	0.10
-0.04	1.62±1.11	0.51±0.42	-	-	-	3	1.16	0.09
2.14	-	0.51±0.42	-1.23±1.16	-	-	3	1.49	0.08
2.35	-	-	-1.23±1.16	-	-	2	1.74	0.07
1.90	1.62±1.11	0.51±0.42	-1.23±1.16	-	-	4	1.80	0.07
-0.07	-	0.51±0.42	-	0.14± 0.95	-	3	1.81	0.07
-0.13	1.62±1.11	-	-	-	0.58±0.86	3	1.66	0.07
MAE	1.62±1.11	0.51±0.42	-1.23±1.16	0.14± 0.95	0.58±0.86			

Int. = intersection; DFRE= Distance from road edge, DFHH-Distance from human habitation, CC=Canopy Cover, SC=Shrub Cover, GC=Ground Cover, df = degrees of freedom; ΔAICc = difference in value of Akaike's information criterion between the focal model and the top-ranked model. MW=Model Weight, MA=Model Average Estimates

that reptiles and amphibians are among the most skilled taxonomic group, while mammals are the least. Some earlier studies also found that amphibians and reptiles were among the most affected groups from the roadkill (Baskaran and Boominathan 2010, Selvan et al 2012, Sur et al 2022).

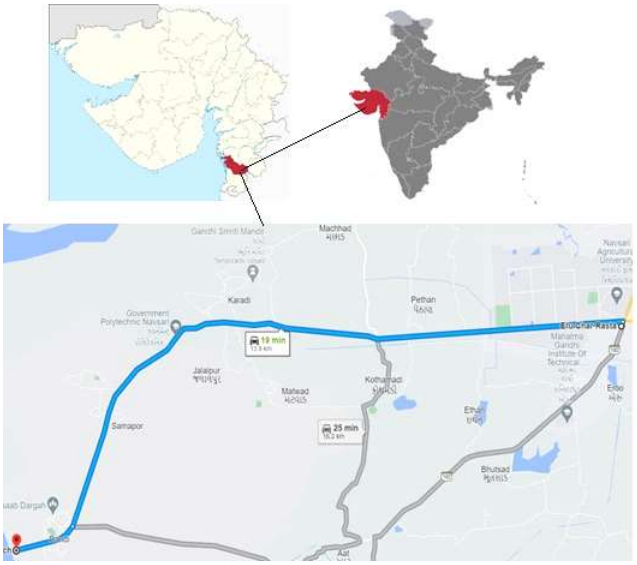

Fig. 1. Map of the study (road in blue)

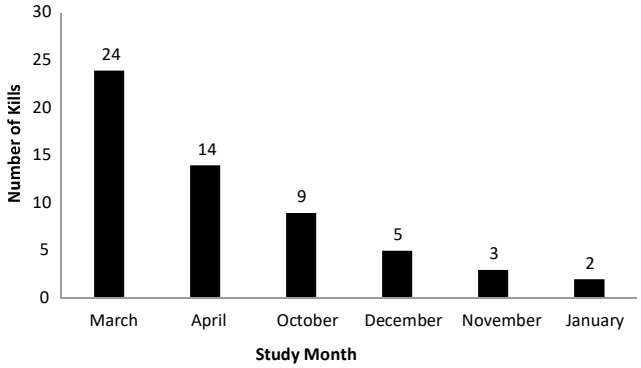

Fig. 2. Distribution of road kill in relation to study month

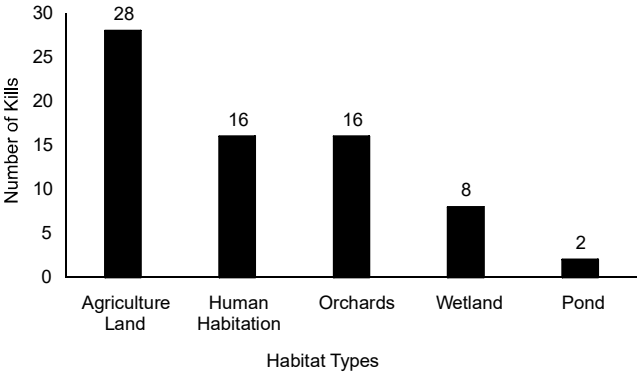

Fig. 3. Distribution of road kills in relation to habitat types

Amphibians and reptiles move slower than mammals and cannot react very quickly to vehicles, leading them to take more time while crossing the roads and increasing the probability of their kills (Row et al 2007, Baskaran and Boominathan 2010, Hatti and Mubeen 2019). The common garden lizard was among the most affected species by roadkill amongst reptiles, while among the amphibians and mammals were a common frog and five stripped squirrels, respectively. The abundance of the species around roads is among the key factors affecting roadkill status (Dutta 2016). Sur et al (2022), while assessing roadkill on the road passing through Kaziranga tiger reserve, found that the most frequently killed species were the generalist and abundant, like common Indian toad and squirrel species. Our study road has ravines and large trees which act as suitable habitats for common species such as frogs and squirrels, respectively. The ravine and large trees provide habitat for the amphibians and squirrels, respectively consequence is their high abundance around the rods, which might lead to their high roadkill. Also, the foraging nature of frogs and toads, which are very fond of gathering near street lamps and vehicle headlights to feast on insects (Daniels 2005) could be one of the possible reasons for their higher susceptibility to becoming roadkill victims. High roadkill of garden lizards could be due to canopy gap, which forces them to cross the

Fig. 4. Some of the roadkill encounter during the survey [clockwise a) Common garden lizard b) Green wine snake c) Five stripped squirrel d) Common Frog]

roads and hence the high number of kills (Sur et al 2022). Among reptiles, apart from one species, i.e., the common garden lizard all other kills were of snake species. Rosen and Lowe (1994) estimated 2383 per 35.5 km year^{-1} of snakes killed by automobiles in the United States. The Later study also stated that resting or coiling snakes on the road surface, especially during the spring season for warmth, contributes to snakes' high road mortality. Snakes use the road surface for thermoregulation, which seems to be the reason for the high death rate of snakes by roadkill (Rosen and Lowe 1994, Vijayakumar et al 2001). Among mammals, Indian gerbils and House rats were among the most killed after five stripped squirrel. Both the Indian gerbil and House rats are nocturnal in their activity pattern. Many more nocturnal mammal species are present in this landscape, like leopards and wild pigs, but gerbils and rats were roadkill victims because they were smaller in size and less noticed on the road by the drivers.

Maximum roadkills happen during March, which is the onset of the summer, which could be due to increased vehicle intensity in March owing to festivals like Holi when people visit Dandi. Otherwise, one could expect more kills during April if the summer season is the reason. However, further research is needed in this direction. The highest roadkill happened when agricultural habitat was in the surroundings. The presence of agricultural habitat possibly led to the high abundance of some species, like Five stripped squirrels that used to feed on crops (Hill 1997). A high abundance of some species might result in increased roadkills around the agricultural habitat.

The generalized linear model suggested that roadkill probability increase with an increase in ground cover, shrub cover, distance from the road edge, and distance from human habitation. In contrast, with an increase in canopy cover, roadkill probability increased, which is in accordance with some earlier studies (Habib et al 2020). Both high ground cover and shrub cover may create a visibility hindrance for both animals crossing the roads and vehicle drivers, which might lead to high kill around high ground and shrub cover areas. Furthermore, studies have found that wildlife across the globe avoids human disturbances (Steffan et al 2015). Possibly areas further to human habitation have a high abundance and richness of species, leading to high crossing by them, and hence high roadkills. Inverse relations of roadkill with canopy cover could be due to high usage by the species like lizards and five-stripped squirrels, which make a maximum of all the kills. With the decrease in canopy cover, the canopy gap increased, leading to high road usage by certain species like squirrels and lizards consequence of which is high roadkills (Sur et al 2021).

CONCLUSION

The present study provides basic information about roadkill. Road widening could increase the magnitude of roadkill, threatening species' survival. The present study will also provide a baseline for future surveys and hence could be helpful to assess the impact of road widening on the roadkill if it happens.

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Taxonomic Richness and Diversity of Epilithic Diatom Flora in a Central Indian River, the Belan, India

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Abstract: A study was conducted in the river Belan (156 km), a north central Indian river of Vindhyan ranges to determine diatom diversity from headwater to mouth. Samples were collected 5 different stations by scraping 3x3 cm^2. area of substratum (stones) during winter season December 2021 to March 2023. The count data were computed diversity indices (Margalef D', Shannon diversity H') and evenness (E). Total of 119 diatom taxa belonging to 28 genera were identified. H and D indices ranged from 2.77 to 2.62 and 26.709 to 18.4979, respectively. Evenness value was 0.81 to 0.77. The gradual decline in diversity and evenness was recorded from S1 to S5 except at S3. The anthropogenic activities impact (agriculture) at S3 was responsible for extreme low of diversity and evenness.

Keywords: Richness, Diversity indices, Diatom, Land use, Belan

Diatoms communities are excellent indicators of modified environments and are found in both freshwater and marine environments as well as in moist soil, on wet surfaces, in unusual places like whale skins, in hot springs or highly basic or acidic environments, ice brine canals (Nautiyal and Verma 2009). The aquatic ecosystems globally face threats due to various anthropogenic disturbance and climate change resulting biodiversity loss in ecosystems(Dudgeon et al 2006). The loss of biodiversity has important implications, diminished resistance , resilience to disturbance, system simplification and loss of ecological integrity (Nautiyal and Verma 2009). Many significant studies have been carried out in the various part of the world. However, in India, separate studies have been conducted in the different ecoregions of Himalaya (Cantonati et al 2001, Nautiyal et al 2004a) central Highland's region (Verma and Nautiyal 2009, Mishra et al 2017) and peninsular region (Karthick et al 2013). Despite of these studies in central Highland's ecoregion, still few sections of central Highland region is lacking about diatom information. The Belan valley is one of the unexplored sections of central Highlands located between the Vindhyan ridges (northern most outliers of the Vindhyas) in the north and Kaimur range in the south. The present study was designed to explore diatom diversity and richness in the river Belan along the river length from unexplored Belan valley section of Central Highlands region.

MATERIAL AND METHODS

Study area: The Belan river as a major water body of the Belan valley along with its other small tributaries like Adwa, Seoti, Lohanda Nala, Tundiari, Gorma and Naina, drains about 7,800 sq km area in the Northern Vindhyas, encompassing parts of Sonbhadra, Chandauli, Allahabad and Mirzapur Districts of Uttar Pradesh, and adjoining areas of the Rewa and Sidhi Districts of Madhya Pradesh. The river Belan originates from Vindhyan ranges in the district Sonbhadra. It is approximatly156 km long and flows towards west-north direction and drains into the river Tons near Chakghat (Fig. 1, Table 1). From headwater to mouth, the river Belan passes from various land use *viz*. forest, agriculture and human habitation (Town/city; Table 1).

Sampling: The diatom samples were collected at five different stations (S1 to S5) from cobble stony substratum (3x3 cm^2 area) by using razor during the winter season from December 2021 to November 2022. The collected samples were preserved in 4% formaldehyde solution, and then cleaned with double distilled water to remove traces of formaldehyde, digested with hydrochloric acid. The treated samples were washed repeatedly with double distilled water to remove all traces of acid. Samples were then cleaned with hydrogen per oxide and distilled water. The processed material was mounted in Naphrax for preparing the permanent slides from each sample for light microscopy. The identification made at genus and species level with help of standard key (Taylor et al 2007, Karthick et al 2013).

Margalef Index (Margalef 1957)

$D' = S-1/\log N$,

Where S = number of species and N = number of individual

Shannon species diversity Index (Shannon and Weaver 1949)

$H = -\sum pi \log pi$

Where pi = ni/N, ni = number of individual of one species and N = total number of organism

Evenness Index (Pileou 1966)

E = H/Log S

H = Shannon Index of general diversity; S= Number of species.

RESULTS AND DISCUSSION

Total 28 diatom genera and 119 species were recorded from S1 to S5 in the Belan river. Among these species, 90, 74 44, 63 and 59 species were observed at S1, S2, S3, S4 and S5, respectively (Table 1). The reduction in substrate heterogeneity attributed to decline of species richness.*Cymbella* was highest species rich genera followed by *Navicula*, *Nitzschia*, *Achnanthidium*, *Gomphonema* and *Fragilaria* (Table 2). Longitudinally,15 genera were distributed at all stations, while 7 were restricted at 4 stations. Similarly, 5 genera were restricted at 3 stations and *Encyonema* species was restricted only at S1 station. The species diversity in each genus varied of along the river S1 to S5 (Fig. 2). Nautiyal and Verma (2009) reported 293 species in Vindhya and 189 species in Himalaya and added that *Navicula* was highest species rich genera followed by *Nitzschia* and *Cymbella* in central plateau river (Bundelkhand). However, in the Himalayan rivers *Navicula* and *Achnanthes* were the most species rich genera (Nautiyal et al 2004a).

The species diversity and evenness varied from S1 to S5. Shannon and Weaver diversity value gradually decreased from S1 (2.7769) to S5 (2.6261) but sudden decline was recorded at S3 (1.1271). Similarly, Margalef diversity indices and evenness also decline gradually from S1 to S5 and abrupt decline at S3 (Table 1). The declining of diversity from headwater to downstream was attributed to shifting of land use patterns from forest (S1, S2) to forest-agriculture (S3), agriculture (S4) and agriculture -human settlements (S5). However, extremely low diversity and evenness was due to river regulation by Pipari Dam at upstream of S3. As the concentration of human intervention increases, the disturbance in ecosystem also increases which impact on

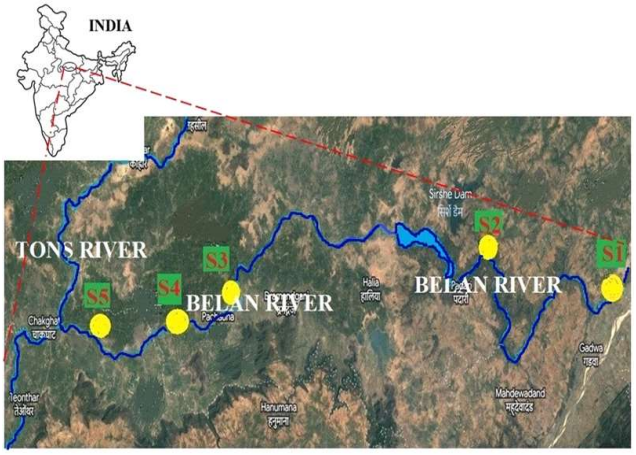

Fig. 1. Location of Belan River in the Indian map. In the topographic map blue line indicates river Belan along with the sampling stations (S1 to S5)

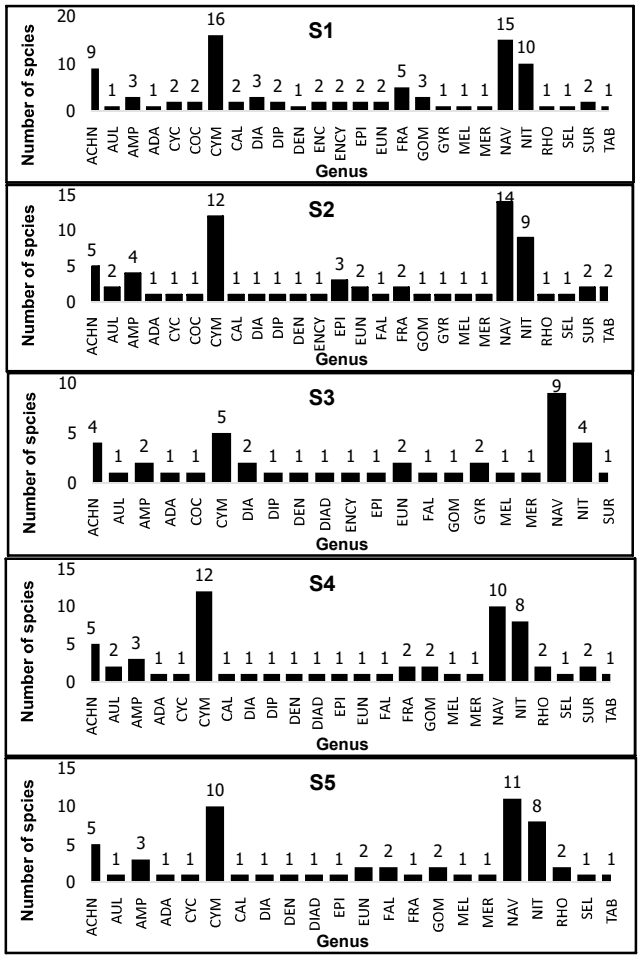

Fig. 2. Distribution of species richness along the river length of Belan from S1 to S5. Acronyms: ACHN-*Achnanthidium,* AUL-*Aulacoseira*, AMP-*Amphora*, ADA-*Adalfia*,CYC-*Cyclotella*, COC-*Cocconeis*, CYM- *Cymbella*, CAL-*Caloneis*, DIA- *Diatoma*, DIP-*Diploneis*, DEN-*Denticula*, DIAD- *Diadesmis*, *ENC-Encyonema,* ENCY-*Encyonopsis*, *EPI- Epithemia,* EUN- *Eunotia*, FAL- *Fallacia*,FRA- *Fragilaria*,GOM-*Gomphonema,* GYR- *Gyrosigma*,MEL- *Melosira,* MER- *Meridion*, NAV- *Navicula*, NIT- *Nitzschia,* RHO-*Rhopalodia*, SEL- *Sellaphora*, SUR- *Surirella*, TAB-*Tabularia*

Table 1. Geographical co-ordinate and diversity -evenness patterns of diatom community at each sampling stations on the river Belan

Stations	S1	S2	S3	S4	S5
Latitude ^{O}N	24°41'45"	24°46'21"	24°54'27"	24°56'32"	25°00'38"
Longitude ^{O}E	82°39'42"	82°33'00"	82°02'14"	82°56'40"	81°47'11"
Altitude (m)	249	200	119	118	113
Substrate	R- G-P-C	R-B-P-C-S	S	P-C-S	C-S
Land use	F	F	F + Ag	Ag	Ag +V
Taxonomic richness	90	74	44	63	59
Shannon diversity (H)	2.7769	2.6516	1.1271	2.6415	2.6261
Margalef diversity (D')	27.3166	22.40	14.1237	19.5088	18.4979
Evenness (E)	0.81647	0.80482	0.3313	0.7766	0.7721

Acronyms: Rocks (R), Boulder (B), Gravel (G), Pebbles (P), Cobbles (C), Sand (S), Forest (F), Agriculture (Ag), Village (V).

Table 2. Generic distribution of diatom flora along the river length from S1 to S5 in the river Belan

Taxa	Number of species	S1	S2	S3	S4	S5
Achnanthidium	9	+	+	+	+	+
Aulacoseira	2	+	+	+	+	+
Amphora	4	+	+	+	+	+
Adalfia	2	+	+	+	+	+
Cyclotella	2	+	+	-	+	+
Cocconeis	3	+	+	+	-	-
Cymbella	17	+	+	+	+	+
Caloneis	2	+	+	-	+	+
Diatoma	3	+	+	+	+	+
Diploneis	2	+	+	+	+	-
Denticula	3	+	+	+	+	+
Diadesmis	2	-	-	+	+	+
Encyonema	2	+	-	-	-	-
Encyonopsis	2	+	+	+	-	-
Epithemia	3	+	+	+	+	+
Eunotia	3	+	+	+	+	+
Fallacia	2	-	+	-	+	+
Fragilaria	7	+	+	+	+	+
Gomphonema	8	+	+	+	+	+
Gyrosigma	2	+	+	+	-	-
Melosira	1	+	+	+	+	+
Meridion	1	+	+	+	+	+
Navicula	15	+	+	+	+	+
Nitzschia	12	+	+	+	+	+
Rhopalodia	2	+	+	-	+	+
Sellaphora	2	+	+	-	+	+
Surirella	4	+	+	+	+	-
Tabularia	2	+	+	-	+	+

organism biodiversity (Nautiyal and Mishra 2012). Nautiyal and Verma (2009) indicated high value of Shannon diversity indices in the Vindhyan river than Himalayan Glacier fed rivers, reported quite variable diversity indices value (0.38-2.74) in Pindar and in Alaknanda (0.64-2.76). The high value of diversity indices indicated the good water quality of the river (Nautiyal and Verma 2009). High taxonomic richness was observed in the forest land use. The changes in land use pattern and velocity caused decline in diversity of diatom community and ecosystem functioning and may lead to altered soil physical and chemical properties. Srivastava et al (2020) reported that changes in land use pattern and velocity influence many ecological processes and substrate heterogeneity and ultimately cause species diversity i.e. higher diversity in forest land use, followed by savanna land, crop land, degraded land.

CONCLUSION

The taxonomic richness and diversity of diatom flora is high in the headwater sections of the river followed by middle and lower section. This study also indicates that the pristine land use like forest (sal forest) and high substrate heterogeneity are responsible for higher diversity. The regulated zone of the river indicates low diversity.

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Evaluation of Air Pollution Tolerance Index of different Tree Species Growing in Jhansi City of Uttar Pradesh

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Abstract: The present study was conducted to screen the pollution tolerant index of nine trees species namely *Azadirachta indica, Cassia fistula, Delonix regia, Dalbergia sissoo, Ficus benghalensis, Ficus religiosa, Holoptelia integrifolia, Nerium indicum,* and *Pongamia pinnata* which are growing either naturally or planted in the Jhansi city of Uttar Pradesh. Samples were collected from the polluted areas of Jhansi city and their test results were compared with the samples collected from the trees growing in the campus of Rani Lakshmi Bai Central Agricultural University Jhansi. The parameters analyzed were total chlorophyll content, ascorbic acid content, relative water content and leaf extract pH. Present study revealed that ascorbic acid content ranged from 0.26 mg/g-3.93 mg/g in polluted sites while under controlled sites ranged from 0.009 to 2.56 mg/g. The highest ascorbic acid content was in *Cassia fistula* (3.94 mg/g) and least in *Dalbergia sissoo* (0.27 mg/g). The total chlorophyll content varied from 0.72-2.20 mg/g. Maximum chlorophyll content was in *A. indica* (2.21 mg/g), whereas, *F. benghalensis* showed least (0.73 mg/g). Under university campus (controlled) conditions *A. indica* recorded with highest total chlorophyll (2.90 mg/g) content and least in *N. indicum* (1.53 mg/g). For leaf extract pH of tree species under study varied from 6.33-8.24. Under Jhansi city sites *F. benghalensis* recorded highest leaf extract pH (8.24) and least was observed in *C. fistula* (6.33). Under controlled condition *F. benghalensis* recorded highest leaf extract pH value 8.09 and lowest in *N. indicum* (6.07). Relative water content of tree species varied from 59.69-84.0%. Jhansi city the highest relative water content was observed for *Ficus religiosa* (84%) and minimum for *A. indica* (59.69%). Under controlled conditions *P. pinnata* recorded highest relative water content of 67.3% and the lowest was found in *A.indica* (46.7%). On comparing the results from two studied sites it was highest APTI values was observed for *C. fistula* (10.30) followed by *F. religiosa* and *F. benghalensis.*

Keywords: Air pollution tolerant index, Trees, Relative water content, Ascorbic acid, Chlorophyll

Air pollution has become an ominous situation to the world. According to the World Health Organization (WHO), each year air pollution is responsible for nearly seven million deaths around the globe. The increased intensity of urban air pollution has become a global issue. The loss of vegetation cover has resulted from the rapid pace of urbanization. Over the last few decades, urban areas have faced increasing environmental stress, particularly from poor air quality, excessive noise, and traffic congestion (Sanesi and Chiarello 2006). The impact of climate change has also increased stress. Road traffic is regarded as one of the most significant sources of air and noise pollution, both of which have negative effects on human health. Pollutant levels in urban air are frequently high, endangering human health and well-being (Kanakidou et al 2011). Plants play an important role in monitoring and maintaining the ecological balance by actively participating in the cycling of nutrients and gases like carbon dioxide, oxygen and also provide enormous leaf area for impingement, absorption and accumulation of air pollutants to reduce the pollution level (Karthiyayini et al 2005, Bemmansou et al 2021). Trees affect air quality through the direct removal of air pollutants, altering local microclimates and building energy use, and through the emission of volatile organic compounds (VOCs), which can contribute to O_3 and Particulate matter (PM) 2.5 formation . Leaves absorb air pollutants through their stomata and catch particles onto their leaves and branches. Numerous reports confirm that the number and size of leaf stomata changes depending on the degree of air pollution and types of pollutant (sulphur, nitrogen oxides and ozone) (Mulgrew and Williams 2000, Shweta 2012). Stomatal response to air pollution is very complex and depends not only on air pollutant concentration and type, but is also very selective depending on plant species (Abeyratne and Ileperuma 2006). An index uses to identify the tolerance of air pollutants was developed which is known as Air Pollution Tolerance Index (APTI). APTI is a species-dependent plant attribute and expresses the inherent ability of plant to encounter stress arising from air pollution. It is mainly based on four major properties of leaves namely ascorbic acid content, relative water content, total chlorophyll content and leaf extract pH . Plant's tolerance to air pollutants generally varies with these parameters. APTI provides a reliable method for screening large number of plants with respect to the vulnerability to

different pollutants. Measuring the air pollution tolerance indices of different plant species has become necessary to mitigate the increased air pollution in urban areas. For this classification of tree species as sensitive or tolerant is critical because susceptible plant species can be used as indicators, whereas tolerant plant species can be used as sinks to monitor air pollution in urban areas (Aghaiee et al 2019). Keeping the above view of importance of tree species to mitigate air pollution in Urban cities, the present study was conducted with the objectives to conduct a survey to identify the air pollution tolerant tree species of Jhansi city and screening out the air pollution tolerance index of selected tree species.

MATERIAL AND METHODS

Study was conducted in Jhansi city and the campus of Rani Lakshmi Bai Central Agricultural University, Jhansi. Jhansi city is located at 25º 43' 33" N to 78º 58' 33" E. A field survey was conducted at three polluted sites of Jhansi city *i.e.* site-I (Railway station), site-II (Bus stand) and site-III (Jhansi zone of Kanpur highway) (Table 1) of Jhansi city to identify the tree species with highest pollution tolerance index.

To study the air pollution tolerance index of selected tree species, 45 leaf samples were collected each tree from a height of 1.5 meters above the ground. The analytical results obtained for the samples collected from the different sites of Jhansi city were also compared with the results obtained for the trees growing under the controlled conditions of RLBCAU, Jhansi. The various studied parameters were total chlorophyll, ascorbic acid, leaf extract pH and relative water content.

The ascorbic acid content was estimated by using method (AOAC 1980).

$$\text{Ascorbic Acid (mg/g)} = \frac{\text{Dye factor} \times \text{Titre reading} \times \text{Volume made}}{\text{Weight of leaves taken} \times \text{Volume taken for estimation}}$$

Leaf extracted pH were estimated by using pH meter (Model- ESICO 1013) with buffer solution of pH 4 and 9 (Barrs and Weatherly 1962). The Total leaf chlorophyll content was estimated using method (Hiscox and Israeistam 1979) using formula:

$$\text{Total chlorophyll content (mg/g)} = \frac{20.0A_{645} + 8.02A_{663}}{a \times w \times 1000} \times V$$

Where, V = Volume of extract made; a = Length of light path in cell (usually 1cm); w = Weight of the sample taken; A645 is absorbance at 645 nm; A663 is absorbance at 663 nm.

Relative water content of the samples was estimated using the method proposed (Singh 1977)

$$\text{Relative water content (\%)} = \frac{FW - DW}{TW - DW} \times 100$$

Where, FW= Fresh weight, TW=Turgid weight, DW= Dry weight of leaf samples

Air pollution tolerance index is an empirical relation which evaluates the tolerance level of plant species towards air pollution from leaf biochemical parameters such as ascorbic acid, total chlorophyll content, leaf extract pH and relative water content and is computed by using the following equation (Singh and Rao 1983).

$$\text{APTI} = \frac{[A(T+P)]+R}{10}$$

Table 1. Coordinates of study area in Jhansi city and RLBCAU campus

Plant species	Jhansi city area			University area (Control)
	Site- I	Site- II	Site- III	
Dalbergia sissoo	25°26'39.1"N 78°34'47.9"E	25°27' 04.6"N 78°34'07.8"E	25°28'08.6"N 78°37' 34.9"E	25º30'42"N, 78º32'32"E
Cassia fistula	25°26'39.7"N 78°34'57.3"E	25°27' 07.7"N 78°34'09.8"E	25° 28'07.3"N 78°37' 36.2"E	25º30'42"N, 78º32'30"E
Ficus religiosa	25°26'36.7"N 78°34'54.3"E	25°27'09.5"N 78°34'1.8"E	25° 28'08.1"N 78°37' 34.4"E	25º30'42"N, 78º32'30"E
Ficus benghalensis	25°26'34.7"N 78°34'57.3"E	25°27'08.7"N 78°33'04.8"E	25° 28'07.3"N 78°37' 34.4"E	25º30'45"N, 78º32'35"E
Azadirachta indica	25°26'35.7"N 78°34'57.3"E	25°27'07.7"N 78°34'09.8"E	25° 28'04.7"N 78°37' 34.2"E	25º30'43"N, 78º32'32"E
Delonix regia	25°26'52.7"N 78°35'48.5"E	25°27'03.5"N 78°34'09.8"E	25° 28'1.3"N 78°37' 39.7"E	25º30'59"N, 78º32'53"E
Holoptelia integrifolia	25°26'34.7"N 78°34'52.3"E	25°27'52.1"N 78°37'22.9"E	25° 28'01.3"N 78°37' 34.9"E	25º30'47"N, 78º32'37"E
Pongomia pinnata	25°26'39.1"N 78°34'47.9"E	25° 27' 26.9"N 78°36'50.8"E	25° 28'04.7"N 78°37' 34.9"E	25º30'50"N, 78º32'41"E
Nerium indicum	25°26'39.7"N 78°34'57.3"E	25°27'07.7"N 78°34'09.8"E	25° 28'1.23"N 78°37' 38.9"E	25º30'50"N, 78º32'37"E

Where, A = Ascorbic acid (mg/g); T = Total Chlorophyll Content; P = Leaf Extract pH; R = Relative Water Content.

RESULTS AND DISCUSSION

Ascorbic acid: Ascorbic acid is important in plant cell wall synthesis, photosynthetic carbon fixation, and cell division. It also serves as a natural antioxidant that has to protect plant tissue from the damaging effects of air pollutants. Because of the high concentration of ascorbic acid, plants are more tolerant to pollution (Agbaire and Esiefarienrhe 2009). There was wide variation in ascorbic acid (mg/g) concentration was among different tree species and the site of sample collection (Table 2). Among the samples collected from the university campus the highest ascorbic acid (2.56 mg/g) was in *Cassia fistula* followed by *Azadirachta indica*, *Holoptelia integrifolia*, *Delonix regia*, *Nerium indicum*, *Ficus benghalensis*, in descending order, respectively. In Jhansi city, site-1 *Cassia fistula* showed highest ascorbic acid content (3.73 mg/g) and minimum was recorded in *Dalbergia sissoo* (0.24 mg/g). *Holoptelia integrifolia* and *Delonix regia, Ficus religiosa, Ficus benghalensis* and *Nerium indicum* had values at par with each other. The result pertaining to site–II varied significantly and the highest value of ascorbic acid was in *Cassia fistula>Azadirachta indica>Delonix regia>Holoptelia integrifolia > Ficus benghalensis> Nerium indicum>Pongomia pinnata>Dalbergia sissoo, respectively*. Data obtained from site-III revealed that highest ascorbic acid concentration was in *Cassia fistula* (4.12 mg/g) which was significantly higher than other species. On comparing trees grown on different sites, the highest ascorbic acid content (0.30 mg/g) was in *D. sissoo* samples collected from Jhansi city, site –III. The minimum was observed in the trees grown in university campus (0.009 mg/g). *Cassia fistula* recorded the highest ascorbic acid value (4.12 mg/g) in Jhansi city, site–III and the minimum (2.56 mg/g) was observed in the trees of same species grown in university campus. *Ficus religiosa* had highest value (0.45 mg/g) in Jhansi city, site –III and the minimum value was observed in university campus (0.009 mg/g).

Ficus benghalensis had the highest value (0.72 mg/g) in the samples collected from Jhansi city site –II. For this species the minimum value was observed in trees growing in university campus (0.31 mg/g). *Nerium indicum* had highest value (0.61 mg/g) at Jhansi city, site –III. The minimum value was observed in university campus (0.36 mg/g). *Delonix regia* had highest value (0.99 mg/g) at Jhansi city, site–I. The minimum value is observed in university campus (0.73 mg/g). *Holoptelia integrifolia* had highest value (1.00 mg/g) at Jhansi city, site –III. The minimum value was observed in university campus (0.764 mg/g). *Pongomia pinnata* had significantly higher value at all sites in Jhansi city compared to campus site. In Jhansi city sites ascorbic acid values were at par with each other. *Azadirachta indica* had highest value (0.99 mg/g) at Jhansi city, site–I. The minimum value was observed in university campus (0.73 mg/g). *Holoptelia integrifolia* showed the highest value (2.13 mg/g) at Jhansi city, site-III. The minimum was observed in university campus (1.7 mg/g). Bharti et al (2018) observed that average ascorbic acid content (mg/g) was in range of 0.6 to 19.6 mg/g. Similar trend was observed by Begum and Harikrish (2010). The trees grown in the polluted site (Jhansi city) had higher ascorbic acid content than the trees grown in control site (University campus). This suggests that trees develop greater tolerance to pollution by increasing ascorbic acid synthesis when exposed to polluted environments (Yannawar and Bhosle 2013, Sahu et al 2020). The significant correlation of ascorbic acid with the APTI value in both the experimental and control sites results are in agreement with other reported studies

Table 2. Ascorbic acid (mg/g) content of tree species in university campus area and Jhansi city area

Plant species	University campus area (Control)	Jhansi city areas		
		Site I	Site II	Site III
Dalbergia sissoo	0.009 ± 0.0001^{lC}	0.24 ± 0.01^{fB}	0.24 ± 0.01^{fB}	0.30 ± 0.08^{eA}
Cassia fistula	2.56 ± 0.0200^{aC}	3.73 ± 0.12^{aB}	3.96 ± 0.01^{aA}	4.12 ± 1.15^{aA}
Ficus religiosa	0.14 ± 0.001^{hC}	0.49 ± 0.01^{dA}	0.31 ± 0.01^{fB}	0.45 ± 0.12^{deA}
Ficus benghalensis	0.31 ± 0.001^{fD}	0.49 ± 0.01^{dC}	0.72 ± 0.06^{dA}	0.63 ± 0.16^{dB}
Nerium indicum	0.36 ± 0.011^{eD}	0.45 ± 0.02^{dC}	0.56 ± 0.02^{eB}	0.61 ± 0.16^{dA}
Delonix regia	0.73 ± 0.005^{dC}	0.99 ± 0.01^{cA}	0.92 ± 0.03^{cB}	0.95 ± 0.26^{cAB}
Holoptelia integrifolia	0.764 ± 0.001^{cB}	1.03 ± 0.03^{cA}	0.99 ± 0.06^{cA}	1.00 ± 0.26^{cA}
Pongomia pinnata	0.22 ± 0.001^{gB}	0.33 ± 0.03^{eA}	0.29 ± 0.05^{fA}	0.355 ± 0.07^{eA}
Azadirachta indica	1.7 ± 0.030^{bC}	1.89 ± 0.03^{bAB}	2.04 ± 0.15^{bAB}	2.13 ± 0.58^{bA}

Different superscripts (capital alphabets) in a column indicates that they are significantly ($p \leq 0.05$) different to each other determined by Duncan's tests; Different superscripts (small alphabets) in a column indicates that they are significantly ($p \leq 0.05$) different to each other determined by Duncan's tests.

(Agbaire and Esiefarienrhe 2009, Meerabai et al 2012, Rupa and Venkatachalam 2017).

Total chlorophyll content Degradation of chlorophyll has been widely used as an indication of air pollution (Ninave et al 2001). In university campus condition highest chlorophyll content was in *Azadirachta indica* (2.88 mg/g) followed by *Cassia fistula*, *Dalbergia sissoo*, *Holoptelia integrifolia*, *Delonix regia* and *Ficus religiosa* in descending order, respectively. At site- I the maximum chlorophyll content was observed in *Dalbergia sissoo* (2.31 mg/g). The chlorophyll content of *Azadirachta indica* and *Cassia fistula* was at par with each other. *Ficus religiosa, Ficus benghalensis* and *Nerium indicum* had least chlorophyll content. At Jhansi city, site- II maximum chlorophyll content was found in *Azadirachta indica* (2.48 mg/g). *Ficus religiosa* and *Nerium indicum* had chlorophyll at par with each other. *Ficus benghalensis* (0.62mg/g) showed least value among all the plant species growing in site II. At site-III the maximum chlorophyll was observed in *Azadirachta indica* (2.21 mg/g) and minimum in *Ficus benghalensis* (0.73 mg/g).

On comparing trees grown on different sites, tree species growing in university campus showed significant lower values for chlorophyll content compared to tree species growing at Jhansi city sites. On the comparative analysis of the chlorophyll content of the tree species from different sites, *Dalbergia sissoo* (2.31mg/g) had maximum value at site-I and minimum was at site-II (1.65 mg/g). The values for *Cassia fistula* were at par for the trees from site-II and site-III. *Ficus religiosa* had maximum chlorophyll content for the samples collected from site-II and minimum was for the samples collected from site-I. For *Ficus benghalensis* site- I and site III had at par values. Total chlorophyll in *Nerium indicum* varied significantly among all sites having maximum (1.31 mg/g) at the site-II and minimum at site- I (0.99 mg/g). *Delonix regia* also followed the same trend as *Nerium indicum*. *Pongamia pinnata* had not shown any significant critical difference in site- III and site- I. *Azadirachta indica* had the highest value at the site-II (2.48 mg/g). The total chlorophyll content was highest in the leaf samples collected from the trees growing in university campus. Tripathi and Gautam (2007) and Mir (2008) also reported a decrease in chlorophyll content in the roadside trees and plants. Air pollutants move into the tissues through stomata and cause partial denaturation of the chloroplast and lessen the pigment content in the cells of polluted leaves of flora. On a comparative analysis of tree species the minimum total chlorophyll content was in leave samples of *Ficus benghalensis* collected from site-II. Similar results were documented by Sinha et al (2017) for *Ficus religiosa* growing at ISBT and Clock Tower which are highly polluted than other sites having lower chlorophyll content than the other species.

Relative water content (%): Relative water content plays a very important role in cell integrity during pollution stress, and in the same way, leaf relative water could have diluted chemical effects of pollutants absorbed by plants during physiological activity to maintain optimum physiological pH for metabolism (Singh and Verma 2007). Among the sample collected from university campus site, maximum value of relative water content was observed in *Pongomia pinnata* (67.3 %) and minimum (46.5 %) in *Azadirachta indica.* In site-I, Relative Water Content maximum was in *Dalbergia sissoo* (87.7%) and *Ficus religiosa* (86%). Both trees had at par value with each other. Minimum value was observed in *Delonix regia* (54.6%). Under site- II condition of Jhansi city area maximum had observed in *Ficus religiosa* (90%) followed by *Ficus benghalensis* (76%) and then *Pongomia pinnata* (71.28%), respectively. *Azadirachta indica* (45.22%) and *Dalbergia sissoo* (45. 88%) showed lowest value in site-II with their value at par with each other. In site-III maximum relative water content observed in *Ficus benghalensis*

Table 3. Total chlorophyll (mg/g) content of plant species in university campus area and Jhansi city area

Plant species	University campus area (Control)	Jhansi city areas		
		Site I	Site II	Site III
Dalbergia sissoo	2.54 ± 0.003^{cA}	2.31 ± 0.24^{aB}	1.65 ± 0.02^{dD}	1.98 ± 0.03^{cC}
Cassia fistula	2.56 ± 0.002^{bA}	1.89 ± 0.26^{bB}	1.64 ± 0.14^{dC}	2.03 ± 0.02^{bB}
Ficus religiosa	2.11 ± 0001^{fA}	0.83 ± 0.16^{eD}	1.34 ± 0.03^{eB}	1.08 ± 0.01^{hC}
Ficus benghalensis	1.95 ± 0.003^{hA}	0.84 ± 0.13^{eB}	0.62 ± 0.02^{fC}	0.73 ± 0.02^{iB}
Nerium indicum	1.53 ± 0.004^{iA}	0.99 ± 0.02^{eD}	1.31 ± 0.02^{eB}	1.15 ± 0.01^{gC}
Delonix regia	2.19 ± 0.0002^{eA}	1.34 ± 0.02^{dD}	1.91 ± 0.03^{bcB}	1.62 ± 0.03^{fC}
Holoptelia integrifolia	2.22 ± 0.0002^{dA}	1.70 ± 0.02^{bcC}	1.96 ± 0.17^{bB}	1.83 ± 0.03^{dBC}
Pongomia pinnata	2.03 ± 0.0002^{gA}	1.63 ± 0.02^{cD}	1.77 ± 0.03^{cdB}	1.70 ± 0.03^{eC}
Azadirachta indica	2.88 ± 0.0002^{aA}	1.94 ± 0.01^{bD}	2.48 ± 0.22^{aB}	2.21 ± 0.02^{aC}

(79.2%) followed by *Ficus religiosa* and *Dalbergia sissoo*. *Ficus religiosa* (76%) and *Dalbergia sissoo* (75.6%) showed their values at par with each other and no critical difference was found. On comparing trees grown on different sites, In Jhansi city site-I, *Dalbergia sissoo* showed significantly highest values (87.7%) compare with the all other site. *Cassia fistula* showed significant values at all sites and highest was in site-I (81%) and lowest (45.8%) in site- II. For *Ficus religiosa* had the highest value (90%) in site- II followed by site-I (86%), site-III (76%) and university area (56%) in descending order, respectively. In *Ficus benghalensis* site-I and site-II had higher values that are at par with each other and minimum value in university campus site (50.51%). *Nerium indicum* had significant value at all sites with maximum in site- II and minimum in site-I. *Delonix regia* also follows the same trend as *Nerium indicum*. *Pongomia pinnata* have at par vales in site-III and site-I. For *Azadirachta indica* had highest value at site-I (75%) followed by site III (58.85%). The water content is higher in polluted site as compared to that of controlled site (Table 4). Tanee et al (2014) reported that plant found near polluted area absorbed more water to sustain physiological activity of the plants to withstand the effect of pollution in its environment. Different finding also suggest that higher relative water content helps plants in maintaining the physiological balance under stress condition. Finding of our studies goes well with earlier findings (Babu et al 2013, Bharti et al 2018, Balasubramanian et al 2018) while comparing Relative water content in polluted site and control site.

Leaf extract pH: pH also influences the photosynthetic efficiency rate in leaves, photosynthetic rate increases in leaves with high pH and reduce in leaves with lower pH value (Lohe et al 2015). High pH may increase the efficiency of conversion from hexose sugar to ascorbic acid, while low leaf extract pH shows a good correlation with sensitivity to air pollution (Escobedo et al 2008,Rehman and Gul 2015,). Thus, the pH of the foliar extract is an indicator of the development of detoxification mechanism in plants necessary for tolerance (Ninave et al 2001). Study have reported that in presence of an acidic pollutant, the leaf extract pH was lowered, and the decline was greater in sensitive species (Scholz and Reck 1977). In university condition *Ficus benghalensis* had highest value (8.03) among all the tree species growing in university campus and Jhansi city sites. *Ficus religiosa* and *Holoptelia integrifolia* was at par value within species. For *Dalbergia sissoo* and *Pongomia pinnata* have not shown any critical difference in their values hence they were at par with each other. *Nerium indicum* (6.07) had least value among all species in university area. In site-I, *Ficus religiosa* (8.33) had a significantly higher value compared with *Ficus benghalensis* (8.12). For *Holoptelia integrifolia, Azadirachta indica, Pongomia pinnata* and *Dalbergia sissoo* shad their values at par with each other. *Nerium indicum, Delonix regia* and *Cassia fistula* had shown lower value without showing any critical difference between eachother. In site-II, *Ficus benghalensis* had highest value followed by *Ficus religiosa* and *Holoptelia integrifolia* with their values at par with each other. leaf extract pH value in site- III was found significantly, highest value was found in *Ficus benghalensis* (8.24 and minimum value (6.32) was recorded in *Cassia fistula*.

On comparing trees grown on different sites, tree growing in campus had shown significantly higher value for *Dalbergia sissoo* than tree growing at Jhansi city area. At Jhansi city *Dalbergia sissoo* had maximum in site -I (7.18). For *Ficus benghalensis* site -II (8.37) show highest value followed by site III (8.24) and then site I (8.12) and lowest value was observed in university area (8.03). *Nerium indicum* had highest value at site-III (6.56) followed by site I (6.41) while site II and university campus showed values at par with each other. *Pongomia pinata* also showed significant value with highest value at site I (7.14) and lowest at site II (6.47). For *Delonix regia* showed highest value in site- II (6.39) and site - III (6.42) with their values at par with each other. In case of *Azadirachta indica* had maximum leaf extract pH value was

Table 4. Relative water content of trees species in university campus area and Jhansi city area

Plant species	Control	Site I	Site II	Site III
Dalbergia sissoo	63.48 ± 1.63^{cC}	87.7 ± 1.22^{aA}	45.8 ± 0.65^{gD}	75.6 ± 0.89^{bB}
Cassia fistula	66.78 ± 1.64^{abC}	81 ± 1.23^{bA}	55.5 ± 0.66^{fD}	73.7 ± 0.85^{cB}
Ficus religiosa	56 ± 1.63^{deD}	86 ± 1.22^{aB}	90 ± 0.61^{aA}	76 ± 0.87^{bC}
Ficus benghalensis	50.51 ± 1.63^{fC}	78 ± 1.24^{cAB}	76 ± 0.65^{bB}	79.2 ± 0.89^{aA}
Nerium indicum	57.32 ± 1.66^{dC}	63 ± 1.21^{eB}	67.8 ± 0.64^{dA}	51 ± 0.91^{gD}
Delonix regia	53.67 ± 1.68^{eC}	54.6 ± 1.22^{fC}	62.8 ± 0.65^{eB}	65.18 ± 0.86^{eA}
Holoptelia integrifolia	64.3 ± 1.63^{bcC}	78.42 ± 1.21^{cA}	67.82 ± 0.63^{dB}	61.2 ± 0.89^{fD}
Pongomia pinnata	67.3 ± 1.62^{aC}	73.65 ± 1.22^{dA}	71.28 ± 0.62^{cB}	69.87 ± 0.88^{dB}
Azadirachta indica	46.5 ± 1.63^{gC}	75 ± 1.24^{dA}	45.22 ± 0.65^{gC}	58.85 ± 0.89^{fB}

found in site- I (7.25) followed by site III (6.73). Least value was observed in university area (6.16) (Table 4). The leaf extract pH of plant species had higher values in polluted site (Jhansi city) as compare to the control site (university campus). This suggest that high leaf extract pH which helps in the conversion of hexose sugar to ascorbic acid, thereby improving resistance to stress caused by air pollution/pollutants improve the resistance against the pollution (Singh and Verma 2007, Miria and Anisa 2013). Findings of studies was also in corroboration to the findings of earlier researchers (Tripathi et al 2020, Muhammed Aji et al 2015, Balasubramanian et al 2018).

Air pollution tolerance index: Air Pollution Tolerance Index (APTI) was significantly higher in Jhansi city when compare with same tree species growing university campus area. At Jhansi city area *Cassia fistula* (10.23) and *Ficus religiosa* (8.77) had maximum at par and minimum (6.47) was recorded in *Nerium indicum*. In case of *Ficus benghalensis* (8.33), *Holoptelia integrifolia* (7.85), *Azadirachta indica* (7.79), *Pongomia pinnata* (7.44), *Dalbergia sissoo* (7.21) and *Delonix regia* (6.85) was at par with each other. In university campus area (control site) *Cassia fistula* (8.90) had highest value among all nine trees taken into consideration. *Holoptelia integrifolia* (7.13), *Pongomia pinnata* (6.92) and *Dalbergia sissoo* (6.36) came after *Cassia fistula* without any critical difference among them having at par value. APTI value of *Azadirachta indica* (6.19), *Nerium indicum* (6.01), *Delonix regia* (5.98) and *Ficus religiosa* (5.73) had lowest values showed at par with each other.

Regional variation of trees toward air pollution was also reported (Lakshmi et al 2008, Agbaire and Esiefarienrhe 2009). The higher APTI value in *Cassia fistula* may be due to increased ascorbic acid production and higher relative water content during pollution stress. The ascorbic acid is the primary factor of defense, and it acts against any oxidative damage to plants in the water stress condition and helps in the synthesis of the cell wall, facilitating cell division. It also helps in photosynthesis and is intricately related to the chlorophyll content of the leaf and hence directs the productivity in plants (Sahu et al 2020). Nayak et al (2015) found that *Cassia fistula* having highest APTI value among different plant species around industrial area and Navsari Agricultural University campus. Similar finding was done by Walia et al 2019 recorded high APTI value of *Cassia fistula* among the selected roadside tree species growing at NH-22 in Himachal Pradesh. Lower APTI value of *Azadirachta indica*, *Nerium indicum*, and *Delonix regia* were also line with the values reported from the trees near cement plant in Coimbattore (Radhapriya et al 2012) and in Visakhapatnam industrial areas (Lakshmi et al 2008).

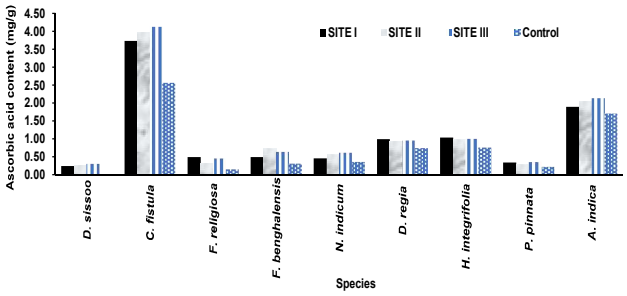

Fig 1. Ascorbic acid content of plant species

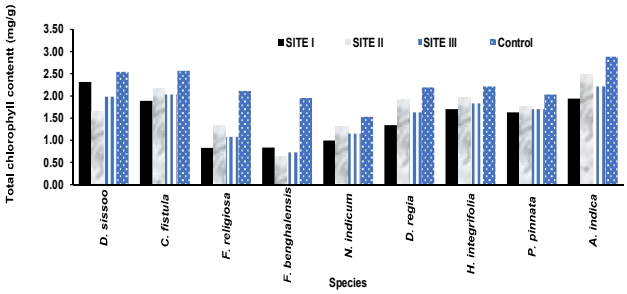

Fig. 2. Total chlorophyll content of plant species

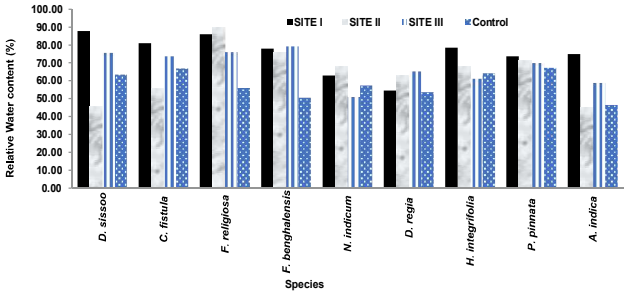

Fig. 3. Relative water content of plant species

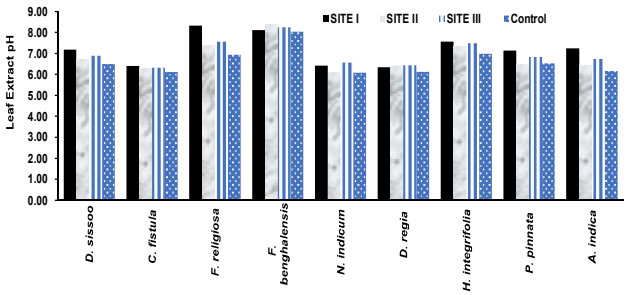

Fig. 4. Leaf extract pH content of plant species

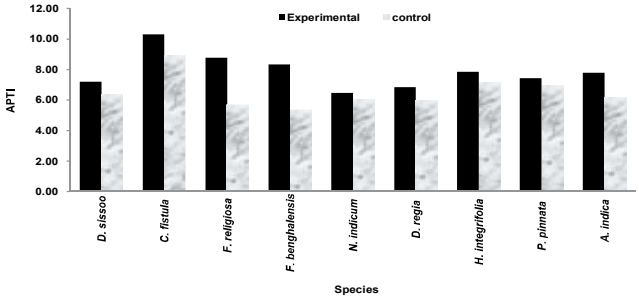

Fig. 5. Air pollution tolerance index of tree species

Table 5. Leaf extract pH of tree species in university campus area and Jhansi city area

Plant species	Control	Site I	Site II	Site III
Dalbergia sissoo	6.49 ± 0.03^{cD}	7.18 ± 0.03^{dA}	6.72 ± 0.02^{cC}	6.88 ± 0.02^{dB}
Cassia fistula	6.1 ± 0.02^{dBC}	6.4 ± 0.20^{eA}	6.28 ± 0.1^{eAB}	6.32 ± 0.02^{iAB}
Ficus religiosa	6.93 ± 0.04^{b}	8.33 ± 0.2^{aA}	7.35 ± 0.01^{b}	7.56 ± 0.04^{bB}
Ficus benghalensis	8.03 ± 0.03^{aD}	8.12 ± 0.02^{bC}	8.37 ± 0.02^{aA}	8.24 ± 0.03^{aB}
Nerium indicum	6.07 ± 0.01^{eC}	6.41 ± 0.01^{eB}	6.09 ± 0.02^{fC}	6.56 ± 0.02^{gA}
Delonix regia	6.11 ± 0.04^{deC}	6.34 ± 0.02^{eB}	6.39 ± 0.02^{dA}	6.42 ± 0.02^{hA}
Holoptelia integrifolia	6.98 ± 0.03^{bC}	7.56 ± 0.03^{cA}	7.33 ± 0.1^{bB}	7.48 ± 0.03^{cA}
Pongomia pinnata	6.52 ± 0.02^{cC}	7.14 ± 0.01^{dA}	6.47 ± 0.02^{dD}	6.83 ± 0.03^{eB}
Azadirachta indica	6.16 ± 0.03^{dD}	7.25 ± 0.01^{dA}	6.4 ± 0.1^{dC}	6.73 ± 0.01^{fB}

Table 6. Air Pollution Tolerance Index of plant species in university campus area and Jhansi city area

Plant species	Jhansi city	University campus
Dalbergia sissoo	7.21±2.18^{b}	6.36±0.08^{b}
Cassia fistula	10.23±1.35^{a}	8.90±0.17^{a}
Ficus religiosa	8.77±0.68^{a}	5.73±1.10^{c}
Ficus benghalensis	8.33±0.14^{b}	5.37±0.55^{d}
Nerium indicum	6.47±0.82^{c}	6.01±0.12^{c}
Delonix regia	6.85±0.56^{b}	5.98±0.44^{c}
Holoptelia integrifolia	7.85±0.88^{b}	7.13±0.44^{b}
Pongomia pinnata	7.44±0.20^{b}	6.92±0.44^{b}
Azadirachta indica	7.79±1.45^{b}	6.19±0.31^{c}
CD (p=0.05)	1.79	0.77

CONCLUSION

According to the findings of this study, all biochemical, physiological, biological, and of plant species play an important role in determining plant sensitivity and tolerance to air pollution, as measured by their tolerance and performance index. Air pollution in urban areas of Jhansi city can be mitigated by developing urban forest or green belts in the city by choosing air pollution tolerant trees. Present study revealed that *Cassia fistula* (10.30), *Ficus religiosa* (8.77) and *Ficus benghalensis* (8.33) would be excellent performers in Jhansi city area. Planners and developers can therefore recommend planting of these tolerant plant varieties for pollution mitigation and greenery enhancement in a Jhansi urban- industrial area.

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Growth, Productivity, and Genetic Variability of Some *Melia dubia* Cav. Open Pollinated Families in Gujarat, India

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Abstract: The growth, productivity, and genetic variability among 17 open pollinated *Melia dubia* families was estimated for 5 years in Gujarat, India. There was significant variation in tree height and DBH growth among families from 1st till 5th year of evaluation. In 4th and 5th year, GJ09 (local family from Northern most tip of Western Ghats, parts falling in Gujarat) achieved significantly maximum height (11.20 and 13.33 m, respectively) and DBH (15.26 and 18.00 cm, respectively) compared other families. Overall, at the age of 5 years, family GJ09, attained highest fresh biomass (30.35 tonne ha^{-1} $year^{-1}$) and volume productivity (29.63 m^3 ha^{-1} $year^{-1}$). The highest GCV, PCV and genetic gain was for tree volume and biomass. All the growth traits recorded maximum heritability values and varied from 60.20 to 74.73 per cent. Among all growth parameters, tree biomass resulted in higher broad sense heritability and genetic gain. There was a strong positive genetic and phenotypic correlation among studied growth traits in *M. dubia*. Values of r_g (0.835 to 0.939) and r_p (0.689 to 0.943) were within the permissible limit for tree height, DBH and volume. Tree biomass was strongly associated with height, diameter and volume.

Keywords: *Melia dubia*, Tree growth, Volume, biomass, Productivity, Genetic variability, Heritability, Genetic advance, Paper pulp

The total forest and tree cover of the country is 80.73 million hectare which is 24.56 percent of the geographical area of the country. Indian forests are having very poor productivity. Against the global average productivity of 2.1 m^3 $hectare^{-1}$ $year^{-1}$, the productivity of Indian Forest is only 0.5 to 0.7 m^3 $hectare^{-1}$ $year^{-1}$ (FSI 2017), while TOFs are producing nearly 3.06 cum per ha per year. Roundwood demand forecast by 2030 in pulp and paper, furniture, plywood and other wood-based industries and construction sector is 12.5, 13.34, 57.49 and 14.48 million m^3 (roundwood equivalent), respectively. These estimates indicate a jump of nearly 70% in demand for roundwood in India in the next decade, from 57 million m^3 in 2020 to 98 million m^3 in 2030, driven largely by the construction sector (Kant and Nautiyal, 2021). Particularly, paper industry in India has an immense potential. Paper consumption in India is projected to grow by 6-7 % per annum in the next five years so as to reach 30 million tonnes by FY 2026 -27 making it the fastest growing paper market in the world (Gupta, 2022). In this backdrop, many efforts have been made to meet wood deficiency by implementing programmes and schemes like agroforestry, social forestry, setting up of state Forest Development Corporations (FDCs) and mission oriented to supply sustain wood to various wood-based industries. Species like Eucalypts, Poplars, Acacias, Casuarinas, *etc*., were introduced, and to some extent, raw material supply was assured. Still inadequate availability of wood for wood-based industries in India is major constraint (Luna et al 2009, 2011, Agarwal and Saxena 2017). Although proven species, may be indigenous or exotic, are relied on vigorously; however, their multipurpose nature is quite limited (Luna et al 2014. Lodhiyal 2014, Chaturvedi et al 2016). In recent years diversified the industries from plywood, paper and pulp, bioenergy, timber for construction, railway, *etc*. Hence, there is very need to look for species which could be utilized for most of the industries at various stages of development.

Melia dubia Cav., an important multipurpose tree, indigenous to Western Ghats region of India, and is common in moist deciduous forests of the Indian. It is also found in Bangladesh, Myanmar, Thailand, Mexico, Sri Lanka, Malaysia, Java, China, America, Philippines and Australia (Mohanty et al 2019). It is short rotation species having multiple uses like very good raw material for ply and pulp wood, plywood industries, high-quality timber for various purposes (Kumar et al 2017, Parthiban et al 2019, Sinha et al 2019) and many other uses like drupe pulp as animal feed (Sukhadiya et al 2019, 2020). It is also considered as an excellent agroforestry species (Jilariya et al 2017, Mohanty et al 2019, Thakur et al 2019, 2020, Prajapati et al 2020) without any allelopathic effect (Kumar et al 2017, Thakur et al 2017, Parmar et al 2020). However, attempts to test progenies of this valuable species are still in infancy stage to develop high

yielding varieties/clones in various parts of the country which are limited to North (Kumar et al 2017) and South India (Parthiban et al 2019). Selection of superior genotypes based on higher values in terms of growth and productivity are generally practiced for large scale multiplication and plantation programme. Therefore, for the first time, we evaluated performance of some open pollinated progenies of *M. dubia* in the Western Indian state Gujarat. The present paper presents the performance of progenies in terms growth, biomass and volume productivity at the age of 5 years as it can be harvested within 4 to 5 years for paper-pulp and for plywood if it has attained minimum diameter (log mid diameter) of 10 cm (Sinha et al 2019, Deepika et al 2019).

MATERIAL AND METHODS

Edapho-climatic conditions of site: The investigation was carried out at the College of Forestry, Navsari Agricultural University, Navsari (20.95°N latitude, 75.90°E longitude with an altitude of 10 m amsl), Gujarat, India, during 2014-2019. Climate of area is characterized humid and warm with monsoon rainfall of around 1500 mm (June-September), moderately cold in winter (November-February) and fairly hot and humid in summer (March-May). Soils of experimental site is deep black originated from old alluvium of basaltic material, taxonomically placed under the group of *Ustochrepts*, sub group of *verti Ustochrepts*, sub order of *orchrepts* and order of *inceptisols*, characterized by clay, deep, moderately drained with good water holding capacity. The soil cracks heavily on drying and expands on wetting and predominant clay mineral found to be montmorillonite. Soil pH and average available nitrogen, phosphorus, potassium, and organic carbon of experimental site was 225.79 kg ha^{-1}, 32.81 kg ha^{-1}, 310.34 kg ha^{-1}, 7.67 and 0.87%, respectively. The average minimum and maximum temperature from 2014 to 2019 was 20.0 and 32.0°C, respectively and average relative humidity and rainfall was 85% and 1570 mm, respectively.

Experimental details: Experiment was conducted in randomized block design with 17 open pollinated *Melia dubia* families as treatments with three replication (three individuals in each replication). The seeds of 16 families were supplied by Division of Genetics and Tree Improvement, Forest Research Institute Dehradun, Uttarakhand, India and family named GJ09 was local source (collected from Northern most tip of Western Ghats), which were collected from South Gujarat, India (Table 1). Planting was carried out in January, 2014 at 3x3 m spacing with boundary row to avoid edge effect. Normal tree management practices were followed to maintain experimental trial. No additional fertilizer (organic or inorganic) was applied throughout the period and trees were allowed to natural pruning after 2nd year onwards.

The tree height and diameter at breast height (DBH; at 1.37 cm above ground) from 2015 to 2019 (1stto 5th years of age) were recorded periodically following standard methods of each family. Standing tree fresh biomass and over bark volume was calculated following regression equations

Table 1. Geographical location of *M. dubia* families tested in the present study

Family No.	Area/Location	Latitude (N)	Longitude (E)	Elevation (ft.)
24	Central Nursery, Forest Research Institute, Dehradun, Uttarakhand, India	30°20'43.3"	78°00'44.2"	2116
28	Central Nursery, Forest Research Institute, Dehradun, Uttarakhand, India	30°20'43.3"	78°00'43.6"	2175
32	Central Nursery, FRI, Dehradun, Uttarakhand, India	30°20'43.6"	78°00'43.7"	2175
69	Forest Area, Dehradun, Uttarakhand, India	30°20'44.6"	78°00'42.1"	2185
75	Central Nursery, Forest Research Institute, Dehradun, Uttarakhand, India	30°20'44.7"	78°00'42.3"	2201
114	Forest Area, Dehradun, Uttarakhand, India	30°20'55.9"	77°59'44.8"	2165
159	Chemistry Division, Forest Research Institute, Dehradun, Uttarakhand, India	30°20'40.1"	78°00'11.6"	2286
195	Forest Area, Dehradun, Uttarakhand, India	30°20'57.3''	77°59'40.2"	2125
233	Forest Area, Dehradun, Uttarakhand, India	30°20'25.4''	78°00'16.9"	2152
263	Forest Area, Dehradun, Uttarakhand, India	30°'20'00.70"	78°00'22.9"	2952
259	Forest Area, Dehradun, Uttarakhand, India	30°'20'31.4"	77°59'33.9"	2180
260	Forest Area, Dehradun, Uttarakhand, India	30°'20'59.4"	77°59'53.6"	2194
261	Forest Area, Dehradun, Uttarakhand, India	31°'32'19.4"	75°53'22.7"	2020
262	Forest Area, Dehradun, Uttarakhand, India	30°'20'00.64"	78°00'22.9"	2134
64	Central Nursery, Forest Research Institute, Dehradun, Uttarakhand, India	30°'24'44.7"	78°00'43.1"	2185
270	Forest Area, Dehradun, Uttarakhand, India	30°'20'04.80"	78°00'29.05"	2270
GJ 09	Nanapodha, Gujarat, India	20˚26.075	73˚ 08.975′	207

$B=0.0299(HD^2)$ +7.48 and $V=0.003 + 0.00003(HD^2)$, respectively (Thakur et al 2021), Where, B =total tree fresh biomass, V=Log volume (Over bark), H=height (m) of the tree and D= DBH (cm). Finally, fresh biomass productivity potential at 5 years age was worked out.

Variability studies: The biometrical analysis was carried out according to the estimation of genotypic and phenotypic coefficients of variation following the method used by Burton and Devane (1953).

Genotypic Variance (GV): $\sigma^2g = (\sigma^2g - \sigma^2e)/r$

r = the number of replications

Phenotypic Variance (PV): $\sigma^2p = (\sigma^2g - \sigma^2e)$

Phenotypic coefficient of variance (PCV): PCV (%) = $\sqrt{\sigma^2p}/\mu \times 100$

Where, σ^2p = Phenotypic variance, μ = population mean of the character

Genotypic coefficient of variability (GCV): GCV (%) = $\sqrt{\sigma^2g}/\mu \times 100$

Where, σ^2g = Genotypic variance, μ = population mean of the character

Heritability: Heritability in broad sense was calculated according to Lush in 1949.

$h^2 = (\sigma^2g/\sigma^2p)$

Genetic advance: Genetic advance is calculated according to Johnson et al (1955).

Genetic Advance (GA) = $h^2 \times \sqrt{\sigma^2p} \times K$

K is the selection differential at selection intensity (K= 2.06).

Statistical analysis: The data generated were subjected to the statistical analysis following Duncan's multiple range test (DMRT) was used to compare the sets of means of each treatment following Sheoran et al (1998).

RESULTS AND DISCUSSION

Height (m) and DBH (diameter at breast height, cm) growth: There was a significant variation in height and DBH growth among studied families from 1st year till 5th year of observation (Table 2). Family 259 attained maximum height from 1st to 3rd year (5.83, 7.90 and9.27 m, respectively). In 1styear, family 75 and in 2nd and 3rd year, family 75 and GJ09 were statistically at par with family 259. In 4th year, family 260 out crossed for height (11.37m) which was at par with GJ09. However, in 5th year, GJ09 achieved significantly maximum height (13.33 m) which was at par with family 260 with height growth of 12.46 m. Family 270 put minimum growth throughout the study period. Results indicated that family 259 attained significantly maximum DBH during 1st to 3rd year (6.26, 11.46 and 13.59 m, respectively). However, at 4th and 5th year, family GJ09 excelled with higher DBH of 15.26 and 18.00 cm, respectively than other families. Family 233

Table 2. Variation in growth of *M. dubia* families at different age gradations in Gujarat, India

Family	Tree height (m)					DBH (cm)				
	Age (Years)									
	1	2	3	4	5	1	2	3	4	5
24	4.73^{bc}	6.97^{abcd}	8.57^{ab}	9.08^{bc}	9.93^{cd}	4.99^{b}	9.71^{bc}	11.35^{bcd}	12.23^{cdefgh}	13.91^{cde}
28	4.12^{cd}	6.19^{bcdef}	7.30^{bcd}	8.55^{cde}	9.92^{cd}	3.29^{efgh}	7.54^{de}	9.74^{defg}	11.27^{fgh}	12.53^{de}
32	2.88^{efg}	5.48^{efgh}	6.81^{def}	7.72^{ef}	8.20^{efg}	2.71^{fghij}	7.06^{def}	9.02^{efg}	10.07^{ghi}	12.63^{de}
69	3.77^{cde}	5.10^{fghi}	6.85^{cdef}	8.88^{bcd}	10.07^{cd}	3.46^{defg}	6.53^{efg}	10.46^{cdef}	11.37^{efgh}	12.00^{ef}
75	5.54^{ab}	6.33^{abcde}	8.60^{ab}	9.83^{b}	11.82^{ab}	4.99^{b}	9.50^{c}	12.00^{abc}	13.15^{abcdef}	15.71^{abc}
114	2.44^{fg}	5.01^{fghi}	6.83^{cdef}	9.40^{bc}	9.97^{cd}	2.59^{fghij}	6.37^{efg}	12.31^{ab}	14.08^{abcd}	15.56^{abc}
159	3.95^{cd}	4.60^{ghi}	6.42^{def}	7.32^{fg}	8.63^{def}	3.50^{def}	7.18^{def}	10.67^{bcdef}	11.49^{efgh}	15.39^{bc}
195	4.33^{c}	7.60^{ab}	8.27^{abc}	9.80^{b}	10.35^{bc}	5.09^{b}	10.40^{abc}	12.21^{abc}	13.82^{abcde}	15.08^{bcd}
233	2.37^{fg}	4.68^{ghi}	5.57^{efg}	8.80^{bcd}	9.58^{cde}	2.07^{j}	5.89^{fg}	8.00^{gh}	10.32^{ghi}	13.69^{cde}
263	4.68^{bc}	5.93^{cdefg}	6.96^{cde}	8.02^{def}	8.53^{def}	3.80^{cde}	8.13^{d}	10.86^{bcde}	12.44^{bcdefg}	13.80^{cde}
259	5.83^{a}	7.90^{a}	9.27^{a}	9.50^{bc}	10.27^{bc}	6.26^{a}	11.46^{a}	13.59^{a}	14.35^{abc}	16.14^{abc}
260	4.53^{bc}	7.43^{ab}	8.48^{ab}	11.37^{a}	12.46^{a}	4.46^{bcd}	11.04^{ab}	13.19^{a}	14.84^{ab}	16.90^{ab}
261	3.30^{def}	5.13^{fgh}	5.50^{fg}	6.40^{gh}	7.17^{fg}	3.18^{efghi}	7.22^{def}	8.92^{fg}	9.82^{hi}	12.74^{de}
262	1.93^{g}	4.14^{hi}	5.53^{efg}	9.27^{bc}	9.62^{cde}	2.23^{ij}	5.41^{g}	9.34^{efg}	11.68^{defgh}	12.04^{ef}
64	2.10^{g}	5.77^{defg}	5.80^{efg}	9.03^{bcd}	10.47^{bc}	2.34^{hij}	6.80^{def}	9.55^{defg}	11.79^{defgh}	13.80^{cde}
270	1.88^{g}	3.67^{i}	4.92^{g}	6.18^{h}	6.80^{g}	2.41^{ghij}	5.25^{g}	6.71^{h}	8.06^{i}	9.64^{f}
GJ 09	4.03^{cd}	7.33^{abc}	8.40^{ab}	11.20^{a}	13.33^{a}	4.62^{bc}	10.83^{abc}	13.27^{a}	15.26^{a}	18.00^{a}

Means with different superscript letter in the same column indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

attained minimum DBH in 1st year, however, from 2nd till 5th year family 270 attained minimum DBH (Table 2).

Fresh biomass (kg tree^{-1} or tonne^{-1}) and over bark volume (m^3 tree^{-1} and m^3 ha^{-1}): Study expressed that, fresh biomass per tree and per hectare differed significantly among the 17 open pollinated families (Table 3). Per tree and per hectare biomass, from 1st to 3rd year, was maximum (14.36, 38.57 and 58.73 kg tree^{-1}, and 15.96, 42.86 and 65.25 tonne ha^{-1}, respectively) among individuals of family 259. However, at 4th and 5th year, individuals of family GJ09put up maximum individual tree fresh biomass (85.48 and 136.60 kg tree^{-1}, respectively) and per hectare as well (94.97 and 151.76 tonne ha^{-1}, respectively). Similarly, per tree and per hectare over bark volume varied significantly among the tested families (Table 4). From 1st to 3rd year, individual tree volume (0.011, 0.035, and 0.055 m^3 tree^{-1}, respectively) as well on hectare basis (11.89, 38.88 and 61.35 m^3 ha^{-1}, respectively) was recorded among individuals of family 259. Whereas, in 4th and 5th year, individuals of family GJ09 achieved maximum over bark volume at individual tree level (0.082 and 0.134 m^3 tree^{-1}, respectively) and per hectare basis (91.17 and 148.15 m^3 ha^{-1}, respectively).

Fresh biomass (tonne ha^{-1} year^{-1}) and over bark volume (m^3 ha^{-1} year^{-1}) productivity: There was a significant variation in productivity potential in terms of fresh biomass (tonne ha^{-1} year^{-1}; Fig. 1) and volume (m^3 ha^{-1} year^{-1}; Fig. 3) of *M. dubia* open pollinated families estimated during 5 years growth period. Since, over 5 years period, family GJ09 put

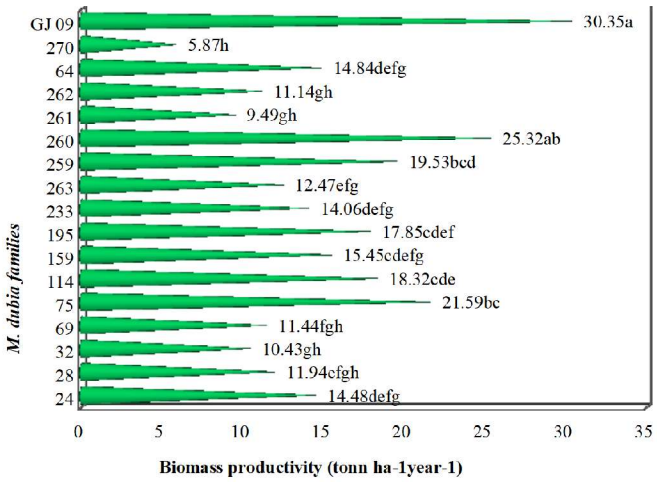

Fig. 1. Variation in biomass (tonne ha^{-1}year^{-1}) productivity potential of *M. dubia* families at the age of 5 years (means with different superscript letter in the same bar indicate significant difference (p<0.05) according to Duncan's Multiple Range Test)

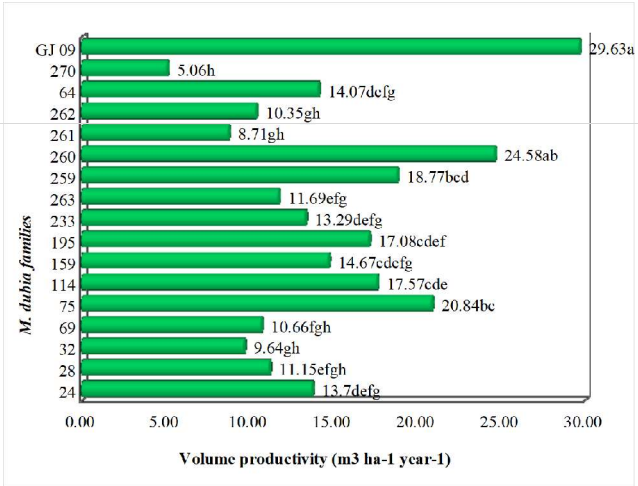

Fig. 2. Variation in volume (m^3 ha^{-1}year^{-1}) productivity potential of *M. dubia* families at the age of 5 years (means with different superscript letter in the same bar indicate significant difference (p<0.05) according to Duncan's Multiple Range Test)

Table 3. Variation in fresh biomass production (kg tree^{-1} and tonne ha^{-1}) of *M. dubia* families at different age gradations in Gujarat, India

Family	Fresh biomass (kg tree^{-1})					Fresh biomass (tonne ha^{-1})				
	Age (Years)									
	1	2	3	4	5	1	2	3	4	5
24	11.01^{bcd}	27.20^{bc}	40.43^{bcd}	48.25^{bcde}	65.15^{defg}	12.23^{bcd}	30.22^{bc}	44.92^{bcd}	53.61^{bcde}	72.38^{defg}
28	8.94^{defg}	18.14^{e}	28.40^{def}	39.97^{defg}	53.72^{efgh}	9.94^{defg}	20.15^{e}	31.55^{def}	44.41^{defg}	59.69^{efgh}
32	8.12^{fg}	16.15^{ef}	24.93^{efg}	31.70^{efg}	46.92^{gh}	9.02^{fg}	17.95^{ef}	27.70^{efg}	35.21^{efg}	52.13^{gh}
69	8.85^{efg}	14.16^{ef}	29.88^{def}	42.29^{def}	51.50^{fgh}	9.83^{efg}	15.7^{ef}	33.19^{def}	46.98^{def}	57.21^{fgh}
75	11.81^{b}	26.09^{cd}	45.19^{bc}	59.38^{bcd}	97.17^{bc}	13.12^{b}	28.99^{cd}	50.20^{bc}	65.97^{bcd}	107.95^{bc}
114	7.97^{g}	13.57^{ef}	39.44^{cd}	67.09^{ab}	82.48^{cde}	8.85^{g}	15.08^{ef}	43.81^{cd}	74.54^{ab}	91.63^{cde}
159	8.99^{defg}	14.80^{ef}	29.48^{def}	36.34^{efg}	69.50^{cdefg}	9.99^{defg}	16.44^{ef}	32.75^{def}	40.37^{efg}	77.22^{cdefg}
195	11.57^{bc}	32.82^{abc}	45.09^{bc}	64.65^{abc}	80.32^{cdef}	12.86^{bc}	36.46^{abc}	50.10^{bc}	71.83^{abc}	89.24^{cdef}
233	7.79^{g}	12.42^{ef}	18.13^{fg}	35.67^{efg}	63.29^{defg}	8.65^{g}	13.80^{ef}	20.14^{fg}	39.63^{efg}	70.3^{defg}
263	9.51^{cdefg}	19.27^{de}	32.22^{de}	44.74^{cdef}	56.14^{efg}	10.57^{cdefg}	21.41^{de}	35.80^{de}	49.70^{cdef}	62.37^{efg}
259	14.36^{a}	38.57^{a}	58.73^{a}	66.14^{ab}	87.89^{bcd}	15.96^{a}	42.86^{a}	65.25^{a}	73.48^{ab}	97.65^{bcd}
260	10.26^{bcde}	34.65^{a}	51.76^{ab}	82.67^{a}	113.95^{ab}	11.40^{bcde}	38.49^{a}	57.50^{ab}	91.84^{a}	126.59^{ab}
261	8.54^{efg}	15.71^{ef}	21.47^{efg}	27.03^{fg}	42.74^{gh}	9.49^{efg}	17.46^{ef}	23.85^{efg}	30.03^{fg}	47.48^{gh}
262	7.79^{g}	11.11^{f}	22.73^{efg}	46.40^{bcdef}	50.14^{gh}	8.65^{g}	12.34^{f}	25.25^{efg}	51.54^{bcdef}	55.71^{gh}
64	7.83^{g}	15.54^{ef}	23.31^{efg}	45.23^{cdef}	66.79^{defg}	8.70^{g}	17.26^{ef}	25.90^{efg}	50.25^{cdef}	74.20^{defg}
270	7.81^{g}	10.53^{f}	14.07^{g}	19.55^{g}	26.39^{h}	8.67^{g}	11.70^{f}	15.64^{g}	21.72^{g}	29.32^{h}
GJ 09	10.09^{bcdef}	33.22^{ab}	51.86^{ab}	85.48^{a}	136.60^{a}	11.21^{bcdef}	36.91^{ab}	57.62^{ab}	94.97^{a}	151.76^{a}

Means with different superscript letter in the same column indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

Table 4. Variation in volume production (m^3 tree^{-1} and m^3 ha^{-1}) of *M. dubia* families at different age gradations in Gujarat, India

Family	Volume (m^3 tree^{-1})					Volume (m^3 ha^{-1})				
	Age (Years)									
	1	2	3	4	5	1	2	3	4	5
24	0.007^{bcd}	0.024^{bc}	0.037^{bcd}	0.045^{bcdef}	0.062^{defg}	8.16^{bcd}	26.21^{bc}	40.95^{bcd}	49.67^{bcde}	68.51^{defg}
28	0.005^{defg}	0.014^{ef}	0.025^{def}	0.036^{efg}	0.050^{efgh}	5.86^{defg}	16.11^{e}	27.54^{def}	40.44^{defg}	55.77^{efgh}
32	0.004^{fg}	0.013^{efg}	0.021^{efg}	0.028^{fg}	0.043^{gh}	4.94^{fg}	13.89^{ef}	23.67^{efg}	31.21^{efg}	48.19^{gh}
69	0.005^{efg}	0.011^{efg}	0.027^{de}	0.039^{ef}	0.048^{fgh}	5.75^{efg}	11.67^{ef}	29.18^{def}	43.02^{def}	53.29^{fgh}
75	0.008^{b}	0.022^{cd}	0.041^{bc}	0.056^{bcde}	0.094^{bc}	9.05^{b}	24.97^{cd}	46.25^{bc}	62.08^{bcd}	104.19^{bc}
114	0.004^{g}	0.010^{efg}	0.036^{cd}	0.064^{ab}	0.079^{cde}	4.77^{g}	11.01^{ef}	39.84^{cd}	70.67^{ab}	87.82^{cde}
159	0.005^{defg}	0.011^{efg}	0.026^{def}	0.033^{fg}	0.066^{cdefg}	5.91^{defg}	12.38^{ef}	28.74^{def}	36.39^{efg}	73.36^{cdefg}
195	0.008^{bc}	0.029^{abc}	0.041^{bc}	0.061^{abcd}	0.077^{cdef}	8.79^{bc}	32.47^{abc}	46.15^{bc}	67.95^{abc}	85.42^{cdef}
233	0.004^{g}	0.009^{efg}	0.014^{fg}	0.032^{fg}	0.060^{defg}	4.57^{g}	9.73^{ef}	16.09^{fg}	35.65^{efg}	66.43^{defg}
263	0.006^{cdefg}	0.016^{de}	0.029^{de}	0.041^{def}	0.053^{efg}	6.49^{cdefg}	17.36^{de}	31.81^{de}	45.75^{cdef}	58.46^{efg}
259	0.011^{a}	0.035^{a}	0.055^{a}	0.063^{a}	0.085^{bcd}	11.89^{a}	38.88^{a}	61.35^{a}	69.61^{ab}	93.86^{bcd}
260	0.007^{bcde}	0.031^{a}	0.048^{ab}	0.079^{a}	0.111^{ab}	7.32^{bcde}	34.51^{a}	53.58^{ab}	88.03^{a}	122.90^{ab}
261	0.005^{efg}	0.012^{efg}	0.018^{efg}	0.024^{fg}	0.039^{gh}	5.40^{efg}	13.40^{ef}	19.81^{efg}	26.02^{fg}	43.52^{gh}
262	0.004^{g}	0.024^{fg}	0.019^{efg}	0.043^{bcdef}	0.047^{gh}	4.56^{g}	8.27^{f}	21.21^{efg}	47.60^{bcdef}	51.78^{gh}
64	0.004^{g}	0.014^{efg}	0.020^{efg}	0.042^{cdef}	0.063^{defg}	4.61^{g}	13.20^{ef}	21.87^{efg}	46.30^{cdef}	70.33^{defg}
270	0.004^{g}	0.013^{g}	0.010^{g}	0.016^{g}	0.023^{h}	4.58^{g}	7.62^{f}	11.58^{g}	17.68^{g}	25.30^{h}
GJ 09	0.006^{bcdef}	0.011^{ab}	0.049^{ab}	0.082^{a}	0.134^{a}	7.13^{bcdef}	32.92^{ab}	53.70^{ab}	91.17^{a}	148.15^{a}

Means with different superscript letter in the same column indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

up maximum growth, volume and biomass production; hence, showed highest fresh biomass (30.35 tonne ha^{-1} $year^{-1}$) and volume (29.63m^3 ha^{-1} $year^{-1}$) productivity potential, which was followed by family 260 (fresh biomass 25.32 tonne ha^{-1} $year^{-1}$ and over bark volume 24.58 m^3 ha^{-1} $year^{-1}$). However, family 270 showed minimum productivity potential. Growth and development of tree species is primarily controlled by several factors such as growth, climatic and edaphic conditions, age and genetic constituent (Khanna, 2015). The study indicated that amongst evaluated open pollinated families, family 259 from 1st year to 3rd year had significantly higher values for tree height and DBH. Finally, at 4th and 5th year, GJ09 gained significantly higher DBH and maximum height at 5th year. Hence, the fresh biomass and over bark volume and productivity potential was highest among the evaluated families in the study. In Northern Indian states of Punjab, Haryana and Uttarakhand, at 3x3 m spacing (at the age of 7 years), *M. dubia* families attained tree height of 9.67 to 16.19 m and DBH of 17.20 to 25.73 cm, individual tree stem under bark volume of 0.104 to 0.255 m^3 and productivity of 23.19 to 55.83 $m^3ha^{-1}year^{-1}$(Kumar et al 2017). The growth and productivity evaluated at the age of 5 years of same families by these workers is higher as compared to that achieved in 7 years. However, family GJ09 out crossed the same family in our study as well as productivity achieved in Punjab, Haryana and Uttarakhand. The variation in growth and productivity of tree species varies from location to location due to edapho-climatic attributes and genetic worth of material (Lodhiyal et al 2002). The better growth and productivity of GJ09 is also attributed to the fact it is local source and well adapted to local edapho-climatic conditions.

The clonal eucalyptus grown in Punjab, India, at 5 years of age (1250 trees/ha) attained height of 19.59 m, DBH of 13.40 cm, individual tree volume of 0.135 m^3tree^{-1} and volume of 168.50 m^3ha^{-1}. Similarly, Luna et al (2009) also reported that eucalyptus clones (12 clones), in 3 years (1666 trees ha^{-1}), acquired height of 10.29-13.97 m, DBH of 7.87-9.82 cm, volume of 0.027-0.052 m^3 $tree^{-1}$, and volume of 44.25-86.41 m^3ha^{-1}. Poplar clones (12 clones) evaluated in Punjab (India) by Luna et al. (2011), at 3 years of age with at 5x4 m spacing, gained the height of 13.50-14.42 m, DBH of 11.58-14.74 cm, individual tree volume of 0.0653-0.1040 m^3tree^{-1}. The above ground biomass for *Eucalyptus* at the age of 5 years (2500 tree ha^{-1}) was estimated to be 52.93 tonne ha^{-1} (Lodhiyal, 2014). Thus, the productivity potential of most of the *M. dubia* families investigated in our study is higher as compared to some of above mentioned industrially important tree species which, in fact, are improved clones.

Tree height and DBH are very important characteristics which indicates the vertical growth and development, and also contributes overall volume and biomass production of the tree (Beck 2010). Height is a good indicator of the adaptability of trees to various growing environmental condition (Kundu 2000). Tree height is one of the important criteria while selection of trees for large scale multiplication (Zobel and Talbert 1984). DBH mainly depends on cambial growth (Spicer and Groove 2010). Selection of superior genotypes based on their higher values in terms of growth, and productivity potential are generally practiced for large scale multiplication and plantation programme. Hence, based on the significant superior growth and productivity of GJ09 can be propagated and further tested for commercial cultivation to achieve higher productivity.

Variability studies: Genotypic variance (σ^2g), Phenotypic variance (σ^2p**)**, Genotypic coefficient of variability (GCV), Phenotypic coefficient of variability (PCV), Heritability (bs) and Genetic advance for growth traits are given in Table 5. In the study, PCV was slightly higher than GCV for height, DBH, volume and biomass. The maximum highest GCV, PCV and genetic gain was recorded by tree volume and biomass than tree height and DBH (Table 6). All the growth traits recorded maximum heritability values and it varied from 60.20 to 74.73 per cent. Such higher heritability values for height, basal diameter and volume index was also recorded in *M. dubia* clones at initial age of growth at field condition (Sathya and

Table 5. Estimates of variance and genetic parameters for growth traits in *M. dubia*

Growth parameter	Height	DBH	Volume	Biomass
σ^2g	2.60	3.58	0.005	1003.50
σ^2p	3.48	5.95	0.007	1462.75
GCV (%)	16.41	13.43	41.01	41.01
PCV (%)	18.98	17.31	49.51	49.51
Heritability (%)	74.73	60.20	68.60	68.60
Genetic advance	2.87	3.03	0.12	54.05
Genetic gain (%)	29.22	21.47	69.97	69.97

N=51 (17 families x 3 replications); DBH, Diameter at Breast Height

Table 6. Phenotypic (above diagonal) and genotypic (below diagonal) correlation among growth traits in *M. dubia*

Growth parameter	Tree height	DBH	Tree volume	Tree biomass
Tree height	-	0.689**	0.851**	0.851**
DBH	0.835**	-	0.943**	0.943**
Tree volume	0.939**	0.946**	-	1.000**
Tree biomass	0.939**	0.946**	1.000**	-

**P ≤ 0.01; DBH, Diameter at Breast Height

Parthiban 2018). In case of *Eucalyptus* clones of 10 years old, the heritability values for height, DBH and volume ranged between 26 to 52 per cent (Behera et al 2017). Therefore, in the study, among all growth parameters, tree biomass resulted in higher broad sense heritability and genetic gain. Hence, this trait may be used while selection best genotypes in *M. dubia.*

Phenotypic (r_p) and genotypic (r_g) correlation coefficient are worked out to understand the relationship between tree height, DBH with volume and biomass in *Melia dubia* (Table 6). There was a strong positive genetic and phenotypic correlation among studied growth traits in *M. dubia.* Values of r_g (0.835 to 0.939) and r_p (0.689 to 0.943) were within the permissible limit for tree height, DBH and volume. The tree biomass was strongly associated with height, diameter and volume. Therefore, maximum tree biomass can be obtained by trees with more height and diameter. Hence, this trait may be considered for selection of genotypes to achieve higher productive potential in *M. dubia*. Such positive relationship among growth traits was also recorded in *M. dubia* (Chauhan and Kumar, 2014), *M. azedarach* (Meena et al 2014) and *Leucaena* (Sangram and Keerthika 2013).

CONCLUSION

There was significant variation in height and DBH growth among families from 1st year till 5th year of observation. In 4th and 5th year, GJ09 resulted in significantly maximum height, DBH, fresh biomass and over bark volume (kg tree^{-1} as well as ha^{-1}) than other families. Thus, family GJ09 put up maximum growth, volume and biomass production; hence, it showed highest fresh biomass and volume productivity potential at age of 5 years. Genetic variability study indicated that PCV was slightly higher than GCV for height, DBH, volume and biomass. Interestingly highest GCV, PCV and genetic gain was recorded by tree volume and biomass than tree height and DBH. All the growth traits recorded maximum heritability values. Therefore among all growth parameters, tree biomass resulted in higher broad sense heritability and genetic gain. Hence, this trait may be used while selection best genotypes in *M. dubia.*

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Effect of Altitudinal Gradation on Population Structure, Composition and Diversity of Non Timber Forest Product Species of Central Western Ghats of Karnataka

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***Abstract*:** Uttar Kannada and Shivamogga districts are situated in the Central Western Ghats of Karnataka and unique in nature by having rich diversity of Non Timber Forest Products (NTFPs) plant species. This paper deals with the population structure, composition and diversity status of NTFP species and these were studied in three altitudinal zones *viz.,* coastal zone (0-250 MSL), midghat zone (251-500 MSL) and plane zone (501-750). Population structure was worked out based on density of seedlings, saplings and adults. Sixty quadrats were laid for the floristic assessment. The vegetation of NTFP composition considered 205 species belonging to 49 families. Importance value index (IVI) recorded highest for *Knema attenuata* (35.49) followed by *Aporosa lindliyana* and *Hopea ponga* at coastal zone. At midghat zone the IVI recorded highest for *Hope aponga* (90.16) followed by *Knema attenuata* and *Garcinia gummigutta* and at plane zone the IVI of *Caryo taurens* was be most dominant (23.70) followed by *Aporosa lindliyana* and *Syzygium cumini.* The coastal zone was very rich in species richness as compared to rest of the altitudinal zones. The richness ranged between 64 (plane zone) to 74 (coastal zone). The diversity of NTFP species highest (3.62) in the Coastal zone followed by midghat zone (2.98) and the lowest was in the plane zone (2.95). The total tree density was highest in the coastal zone (616.25ha^{-1}) while, plane zone recorded the least (608.75 ha^{-1}). But basal cover was maximum at midghat zone (1485.77 m^2 ha^{-1}) and minimum for plane zone (502.19 m^2 ha^{-1}). The study suggested that structure, diversity and species richness are regulated by physiographic and climatic factors along the gradient.

***Keywords*:** Population structure, Altitudinal gradation, Plant diversity, NTFPs

The forests are characterized by high species richness, biomass and productivity. The nature of forest communities depends on the ecological characteristics in sites, species diversity and regeneration of species (Rahman et al 2011). The Southern peninsular region of India along its Western coastline has a long ridge of mountain ranges called Western Ghats. These mountain ranges in the state of Karnataka stretch from Dandeli in the north to Mangalore in the south, and from the edge of the western coastline they go as far as Coorg and Madikeri. Western Ghats of India is one of the biodiversity hotspots of the world. They are well known for their rich and unique assemblage of flora and fauna. It has dense and valuable forests and based on various field based analysis of vegetation communities, there are basic forest types found in Western Ghats: evergreen, semi-evergreen, dry deciduous and moist deciduous (Bhat et al 2000). It has records of over 7,402 species of flowering plants, 1,814 species of non-flowering plants are known from the Western Ghats (Nayar et al 2014). Altitude is one of the most important determinants of structure of the vegetation due to its direct influence on the microclimate of the habitat (Adhikari et al 2012). The duration of dry months and altitudinal variations controlled the structure of the vegetation in the Western Ghats. Altitude in terms of elevation above sea level plays a vital role in the health and growth development of vegetation. As it affects the quality and quantity of sunlight that plants receive, the amount of water that plants can absorb and the nutrients that are available in the soil. As a result, certain plants grow very well in high elevations, whereas others can only grow in middle or lower elevations. Even the slightest change in altitude causes great differences in the growth and development of vegetation in the area.

Population structure of tree species reflects its ecological and biological characteristics (Da et al 2004) and is expressed as a direct impact on the community structure which in turn indicated the development trend of the community (Xia et al 2004). The most commonly used size variable in the analysis of population structure, height class distribution for seedlings and saplings is diameter/girth at breast height (DBH/GBH) which is also used for the study of population structure of tree species (Bharali et al 2012). The inclusion of seedlings and saplings would provide better information about the status of the species at early stage of regeneration. Non-Timber Forest Products (NTFPs) are source of subsistence, employment and income for of people living in and around the forests and also provide food and

livelihood security particularly during droughts and famines. In recent years, human developmental activities have posed increasing threats to biological diversity of forest zones all over the world. Forests are subjected to a variety of disturbances during extraction of NTFP and this exploitation impact on forest community varies with the intensity and mode of extraction (Ticktin 2004). The collection of larger quantities, for commercial or any other purpose, can lead to over-exploitation, decreased local abundance, and extinction of some species that provide highly desired products (Dao and Holscher 2018). Collection of few fruits and harvesting of leaves may have negligible impact on plant population being exploited but intensive exploitation of seeds, flowers and fruits may lead to reduced species richness of community.

MATERIAL AND METHODS

The study was carried out along altitudinal gradation from the coast (Kumta taluk Uttar Kannada District) through mid ghat of Siddapur in Uttar Kannada to plains (Soraba taluk, Shivamogga District). The study site falls (14°23' N to 14°23'38"N and 74°48'E to 74'38"E) under the administrative jurisdiction of Canara Forest Circle, represented by Siddapur Forest Range in the Sirsi territorial Forest Division, Kumta and Gersoppa forest ranges in the Honnavara territorial Forest Division and Shivamogga Forest Circle, represented by Soraba Forest Range in the Sagar territorial Forest Division. The altitude varies from 0 to 750 m above sea level. In the present study, the data was collected by following systematic survey in the entire study area. Thus before commencing the field assessment work, the grid cells of 5 km^2 were laid on the map of reserve area using GIS tools. In each of these grids, phytosociological studies, different demographic parameters (tree density, regeneration etc.) and mainly the abundance data of the NTFP species were collected by laying quadrats. The study area was divided into three vegetation strata that occurred between 0-250 m, 251-500 m, and 501-750 m. Survey was undertaken and vegetation in relation to altitudinal gradient was demarcated. Quadrate sample plot method was adopted for analyzing vegetation composition of all types. Total of 60 sample plots were laid out to gather information on the density, population structure and regeneration of species. Vegetation was studied through sampling within three Ecological Zones (Coastal, Mid ghat, Plane). In each altitudinal zones a total of twenty quadrates of size 20 × 20 m were laid systematically at different localities. For assessing the tree diversity layer, quadrates of size 20 × 20 m were laid and at each sample point, all the trees ≥ 30 cm (gbh) within the quadrates were identified and measured. Importance value index (IVI) of each species was calculated by summing relative frequency, relative density and basal area as per Curtis (1959). Diversity indices were calculated as per Ludwig and Reynolds (1988).

RESULTS AND DISCUSSION

Composition and structure: Vegetation was studied through sampling within three ecological zones. Selected top ten species and last five species in the entire three zones. The coastal zone exhibited a luxuriant growth. This zone is very rich in species diversity with as many as 74 woody species. Among all the species, *Knema attenuata* was most frequent species exhibiting higher frequency of 65 per cent followed by *Aporosa lindliyana*, *Hopea ponga* and *Myristica malabarica*. *Knema attenuata* superior (67.50 trees/ha) followed by *Aporosal indliyana* and *Hopea ponga*. The highest basal area was for *Knema attenuata* (93.25 m^2 ha^{-1}) followed by *Hopea ponga* and *Aporosa lindliyana*. Importance value index highest for *Knema attenuata* (35.49) followed by *Aporosa lindliyana* (27.37) *Hopea ponga* at Coastal zone (Table 1). The species frequency among various species ranged between 5 to 75 per cent. *Knema attenuata* was most frequent species (75%) followed by *Hopea ponga* , *Garcinia gummigutta* and *Aglaiae laegnoida*. The basal area was , highest for *Hopea ponga*(890.17 m^2 ha^{-1}) followed by *Garcinia gummigutta* and *Knema attenuata* . The importance value index highest for *Hopea ponga* (90.16) followed by *K. attenuata* and *Garcinia gummigutta* (Table 2).

The frequency among various species ranged between 5 to 70 per cent. *Caryota urens* most frequent species (70%) followed by *Aporosa lindliyana*, *Mangifera indica* and *Ixora brachiata*. *Aporosa lindliyana* was superior with highest number of trees (41.25 trees ha^{-1}) followed by *Terminalia paniculata* and *Caryota urens*. *Syzygium cumini* possess highest basal cover followed by *Caryota urens* and *Aporosa lindliyana.* In terms of importance value index *Caryota urens* was most dominant (23.70) followed by *A. lindliyana* and *Syzygium cumini* (Table 3).The stand density exhibited wide range of variations among communities of various altitudinal zones of the study area. The total tree density was highest in the coastal zone (616.25 trees/ha) while, Plane altitudinal zone (501-500 m MSL) recorded the least (585 trees/ha). But basal cover was maximum at midghat zone (1485.77 m^2/ha) and minimum at plane altitudinal zone (502.19 m^2/ha) (Table 4). This may be the due to basal area contribution is very dependent on the presence of large individual trees within the sample areas. Similarly these results are in line with Inamati et al (2005) who recorded that basal cover and species richness was highest in fourth altitudinal zone (401-500 m MSL).

The composition of three altitudinal zones was carried out

in the entire area and composed of 49 taxonomic families represented by 205 species across all three altitudinal zones located between 0 to 750 m MSL (Table 5). Among the altitudinal zones, the vegetation of the coastal zone (0-250 m MSL) was richest in floristic and family composition (144 and 42 species) followed by midghat zone (251-500 m MSL) representing 117 and 39 species, and the least (103 and 36 species) was recorded by the plane zone (501-750 m MSL). The variation in quantitative parameters of forest composition among all the studied altitudinal zones may be due to difference in climatic, physiographic and edaphic factors as supported by Sharma et al., (2017). Malik and Bhatt (2016) also reported a total of 44 tree species of 36 genera and 25 families were recorded from the Western Himalaya.

Species richness and diversity parameters gradient (0 - 150 m MSL) is depicted in Table 2. The species richness ranged between 64 (Plane zone). The various diversity indices calculated for NTFP tree species along the altitudinal ne) to 74 (Coastal zone). The plane zone is poor in species

Table 1. Tree layer structure of NTFP species at Coastal zone (0-250 m)

Rank	Species	Density/ha	Frequency %	BA/ha (m^2)	IVI
1	*Knema attenuate*	67.50	65	93.25	35.49
2	*Aporosa lindliyana*	60.00	50	65.41	27.37
3	*Hopea ponga*	43.75	50	78.34	27.28
4	*Myristica malabarica*	26.25	50	29.36	14.78
5	*Syzygium caryophyllatum*	35.00	10	28.91	12.33
6	*Garcinia indica*	30.00	35	17.90	11.71
7	*Mammea suriga*	25.00	10	28.32	10.59
8	*Caryota urens*	17.50	35	17.28	9.56
9	*Cinnamomum verum*	16.25	40	15.02	9.39
10	*Terminalia paniculata*	16.25	25	19.89	8.93
70	*Symplocos racemosus*	1.25	5	0.01	0.68
71	*Ficus racemosa*	1.25	5	0.01	0.68
72	*Bridelia retusa*	1.25	5	0.01	0.68
73	*Embelia ribes*	1.25	5	0.01	0.68
74	*Albizia chinensis*	1.25	5	0.01	0.68

Table 2. Tree layer structure of NTFP species at Midghat zone (251-500 m)

Rank	Species	Density/ha	Frequency %	BA/ha (m^2)	IVI
1	*Hopea ponga*	151.25	70	890.17	92.33
2	*Knema attenuata*	85	75	180.41	34.21
3	*Garcinia gummigutta*	61.25	65	197.22	30.36
4	*Garcinia morella*	48.75	55	39.49	16.61
5	*Aglaiaela egnoida*	28.75	65	45.44	14.81
6	*Dipterocapus indicus*	13.75	15	59.60	7.89
7	*Ixora brachiata*	12.5	45	3.14	7.13
8	*Reinwardtiodendron anamalaiencse*	20	25	11.76	6.78
9	*Myristica dactyloides*	11.25	20	6.36	4.44
10	*Persea macrantha*	7.5	25	5.38	4.30
61	*Arenga wightii*	1.25	5	0.02	0.75
62	*Calophyllum inophyllum*	1.25	5	0.01	0.75
63	*Mallotus philippinsis*	1.25	5	0.01	0.75
64	*Ventilago maderaspatana*	1.25	5	0.01	0.75
65	*Calycopteris floribunda*	1.25	5	0.01	0.75

richness as compared to rest of the altitudinal zones. However, the tree species diversity is higher in coastal zone as compared to other zones. The value of tree species richness in the present study may be attributed to anthropogenic pressures such as extraction of minor forest produce (fruits, seeds, leaves etc.) and cattle grazing. The species diversity of NTFP species highest (3.62) in the coastal zone followed by midghat altitudinal zone and the lowest in the plane zone (2.95) (Table 6). The dominance of tree species was more in coastal altitudinal zone as compared to all other altitudinal ranges. The dominance was inversely proportional to species diversity in all the three altitudinal zones (Fig. 1). Conversely, Simpson's dominance index and the number of species exploited were highest for Plane zone, signifying the predominance of fewer NTFP species at this site. It is hypothesized that the NTFP spectrum reflects the floristic richness of a locality, which in turn, is dependent on the magnitude of disturbance that a site experiences. Although strong association between the local environment and plant community composition have been reported (Muraleedharan et al 2005) in areas subjected to considerable anthropogenic influence. Presumably, locations such as plane zone where a higher number of species were extracted may suffer far greater disturbances than other zones; particularly coastal zone Thus, floristic richness of a forest may be strongly impacted by the magnitude of NTFP extraction. Less disturbed zone showed higher species richness and density than more disturbed (Egbe and Tsamoh, 2018). The present study, therefore, suggests that NTFP extraction, as other forms of human induced disturbances, is related to decline in species richness and a greater magnitude of such disturbances, leads to a greater potential for species loss. This study was devoted primarily to NTFP diversity as measured by species

Table 5. Species composition of NTFP species

Altitudinal gradation	Values of floristic composition	Values of family composition
Coastal zone (0-250)	144	42
Midghat zone (251-500)	117	39
Plane zone (501-750)	103	36

Table 3. Tree layer Structure of NTFP species at Plane zone (501-750 m)

Rank	Species	Density/ha	Frequency %	BA/ha (m^2)	IVI
1	*Caryota urens*	38.75	70.00	56.57	23.70
2	*Aporosa lindliyana*	41.25	60.00	50.24	22.03
3	*Syzygium cumini*	26.25	40.00	59.51	19.66
4	*Terminalia paniculata*	40.00	50.00	36.76	18.31
5	*Mangifera indica*	22.50	55.00	32.67	14.92
6	*Aglaiaelaegnoida*	26.25	35.00	37.28	14.81
7	*Teminalia tomentosa*	27.50	35.00	33.75	14.33
8	*Artocarpus hirsutus*	17.50	45.00	25.72	11.85
9	*Stereospermum personatum*	16.25	35.00	28.98	11.45
10	*Ixora brachiata*	20.00	55.00	7.65	9.51
66	*Albizia odoratissima*	1.25	5.00	0.01	0.63
61	*Chukrasia tabularis*	1.25	5.00	0.01	0.63
62	*Dalbergia latifolia*	1.25	5.00	0.01	0.63
63	*Holarhena antidysentrica*	1.25	5.00	0.01	0.63
64	*Pandanus* species	1.25	5.00	0.01	0.63

Table 4. Density and basal area of woody component of the vegetation in relation to different altitudinal zones

Vegetation strata (m MSL)	Density/ha			Tree basal area/ha (m^2)
	Establishment	Tree	Total	
Coastal zone (0-250)	32770	616.25	33386.25	507.37
Midghat zone (251-500)	26470	608.75	27078.75	1485.77
Plane zone (501-750)	29890	585	30475	502.19
Mean	29710	603.33	30313.33	831.78

Table 6. Key diversity values of NTFP species in different altitudinal zones

Parameters	Diversity values		
	Coastal zone (0-250 m MSL)	Midghat zone (251-500 m MSL)	Plane zone (501-750 m MSL)
Species richness	74	65	64
No of individuals	493	487	468
No of genus	59	46	41
Total basal area (sq.m)	507.37	1485.77	502.19
Shannon-Weiner index	3.62	2.98	2.95
Simpson index	0.04	0.03	0.03
Evenness index	0.88	0.84	0.71
Margalef's index	3.33	2.95	2.94

Table 7. Species similarity indices among different altitudinal zones of the vegetation

Altitudinal zone (M MSL)	Coastal zone (0-250)	Midghat zone (251-500)	Plane zone (501-750)
Coastal zone (0-250)	-	61.87	56.52
Midghat zone (251-500)	-	-	44.96
Plane zone (251-750)	-	-	-

richness and Shannon diversity along the altitudinal gradient. The species similarity among different altitudinal ranges of study area was assessed and community species composition coefficients were determined based on species composition of three altitudinal zones (Table 7). The percentage of similarity among three altitudinal zones varied between 44.96 (plane and midghat zones) and 61.87 (coastal zone and midghat zone). The coastal and midghat zone recorded highest similar species (61.87) followed by plane and coastal zone (56.52) and least percentage of similar species recorded in plane and mid ghat zone (44.96).

CONCLUSION

The study provides useful information on the present condition of the woody species diversity, structure and regeneration status of NTFP species along different altitudinal gradation. The present study highlights the lower elevation (Coastal zone) NTFP species had comparatively higher number of species, whereas lower number of species was recorded at higher elevation (Plane zone) NTFP species, which imply the climatic adaptation by plant species. It is found that altitude affect population structure. The fluctuation in population density of seedlings, saplings and adults along the altitudinal gradation may be linked with the environmental factors. The findings of this study will provide the baseline data to assess future migration of species. Vegetation response to recent climatic changes on NTFP species is dependent on initial species composition, vegetation structure and environmental conditions. Thus to reduce pressure on NTFP population, creating awareness among local peoples in harvesting techniques of NTFP species.

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Phenotypic Variation in Leaves of *Santalum album* L.

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***Abstract*:** Considerable variation have been noticed in the leaf traits of sandalwood in 1997. Until now, only a limited number of studies have been made to describe the leaf phenotypic variation. The present study was conducted in a compact sandalwood population at the Institute of Wood Science and Technology, Bengaluru, India in June 2022 for phenotypic variation in the leaf of sandalwood. The 20 mature trees with 20 leaf parameters for the assessment of phenotypic variation in leaves were selected. Leaves were categorized into nine phenotypic traits, based on their variation in size and shape, such as big ovate, big lanceolate, big elliptic, medium ovate, medium lanceolate, medium elliptic, small ovate, small lanceolate, and small elliptic. The leaf parameters varied significantly, the leaf length ranged from 2.50 to 11.50 cm, and the breadth from 1.00 to 4.50 cm. Leaf parameters were very useful for better understanding the sandalwood phenotypic variation at the taxonomic level.

Keywords: Leaf, Phenotypes, Sandalwood, Variation, Traits

Indian sandalwood is the world's second most valuable tropical heartwood species (Arun Kumar 2016). The population of sandalwood is dwindling due to the selective removal of mature trees in the wild and it is categorized as a “vulnerable” species by the IUCN (Arun Kumar 2019). As quantification of variation and selection of superior phenotypes are important steps in the improvement of any tree species, the IWST (erstwhile Sandalwood Research Centre), Bangalore in 1977-78 has initiated studies to document variation in leaf, heartwood, and oil. Badami and Venkata Rao (1930) made a study to classify the variation into several varieties to evolve a spike diseases resistant strain of sandalwood. The phenological characteristics of sandalwood especially leaf traits have been deciphered by Kulkarni (1994). Initially, some of the leaf variation were suspected of spike disease, which induces different leaf modifications at various stages of infection (Badami and Venkata Rao 1930). Plants are sessile organisms and can adjust their phenotypic and physiological characteristics with environmental heterogeneity (Matesanzet al 2010). This adaptation mechanism occurs in two possible ways: local adaptation and phenotypic plasticity (Palacio-López et al 2015). Phenotypic plasticity is one of the most considerable mechanisms in plants, responding to various climatic conditions (Matesanz et al 2010, Stotz et al 2021), as evolutionary mechanisms cannot always keep up with climate change (Vázquez et al 2015).

Effects of these plastic responses in several important ecological traits *Viz.,* morphology, physiology, anatomy, and phenology are well documented (Sultan 2000, Valladares et al 2007). One of the prevalent results of phenotypic plasticity is prominent variation in leaf shape and size (Chitwood 2016, Tsukaya 2018). Phenotypic plasticity is the ability of a genotype to produce different morphological and physiological responses when exposed to different environmental conditions (La´zaro-Nogal et al 2015, Aranda 2017). These different environmental conditions can result in morphological and physiological leaf trait differences (Niinemets and Kull 2001, Sanches et al 2010, Matheus et al 2018). Accordingly, many studies have noted leaf phenotypic responses along various environmental factors, such as temperature (Atkin 2005, McKee et al 2019), precipitation (McDonald et al 2003, Meier and Leuschner 2008) and light (Grassi 2001, Coble 2014). Classification based on leaf types is subjective and may also depend on individual preference. Moreover, a single parameter alone does not adequately reflect the overall phenotypic expression. For these reasons, phenotypic characterization based on numerical criteria has become a common tool to identify and classify morphological characters in taxonomy (Rakonjac et al 2010). Characterization of leaf morphology with many parameters may add additional knowledge to numerical taxonomy. Hence, this study was conducted to describe the phenotypic diversity of leaves in sandalwood.

MATERIAL AND METHODS

Study area: The present study was conducted in a compact sandalwood population at the Institute of Wood Science and

Technology, Bengaluru, India (N 13^{0}00'67.5" and E 77^{0}34'20.6") in June 2022. The elevation of the study site is 874m. The mean maximum and minimum temperature range from 21.0 to 33.0 °C. The annual rainfall is 102.9 cm (Fig. 1).

Sampling and data collection: The sandalwood population is distributed in about 7ha of land. In the 1990s, it was considered one of the best natural population in India. The age of trees is> 10 years old, and the mean girth and height of sandalwood trees are 42.58 cm (GBH) and 6.63 m respectively. In the present study, 20 trees with uniform canopies were randomly selected based on crown shape and size. From each selected tree, leaves were collected in 5 replications, of which 5 leaves in each replication and totally 25 leaves in the middle portion of the crown, from all directions, for morphometric characterization. The mature leaves were categorized into three groups, based on the size of the leaf *Viz.,* Big, Medium, and Small. In each leaf size class, three types were considered based on their leaf shapes *Viz.,* Ovate, Lanceolate, and Elliptic. The morphological variation in 20 parameters were presented in Table 1, Figure 2 (Abdus et al 2011, Runan et al 2022).

Data analysis: An MS Office Excel version of 2021 was used to analyse the recorded data. Descriptive statistics (mean, standard deviation) for quantitative parameters and one-way analysis of variance were used to test the significant difference among leaf traits for all the quantitative parameters. Coefficients of variation (CV) were calculated to compare relative variation in each leaf parameter and correlation matrix among the parameters was calculated. QGIS version of 3.24.0-Tisler was used to make the study map and to document good-quality pictures we used a DSLR- D90 (NIKON) camera.

Table 1. List of the quantitative parameters used for characterization of sandalwood leaves

Parameters	Measurement unit and description
Leaf Length (LL)	Measuring scale in cm
Leaf Middle Width (1/2) (LMW)	Measuring scale in cm
Leaf Upper Quarter Width (3/4) (LUQW)	Measuring scale in cm
Leaf Down Quarter Width (1/4) (LDQW)	Measuring scale in cm
Leaf Tip Angle (LTA)	Protractor in degree
Leaf Tip Type (LTT)	Taxonomy books and monographs
Leaf Base Angle (LBA)	Protractor in degree
Leaf Base Type (LBT)	Taxonomy books and monographs
Petiole Length (PL)	Measuring scale in cm
Petiole Type (PT)	Taxonomy books and monographs
Leaf Area (LA)	Graph sheet in cm^2
Leaf Perimeter (LP)	Thread in cm
Leaf Margin (LM)	Taxonomy books and monographs
Leaf Shape (LS)	Taxonomy books and monographs
Leaf Color (LC)	Visual observation
Leaf Thickness (LT)	Digital caliper in mm
Petiole Color (PC)	Visual observation
Vein Color (VC)	Visual observation
Leaf Area and Perimeter ratio (A/P)	Mathematical formula
Leaf Length and Breadth ratio (L/B)	Mathematical formula

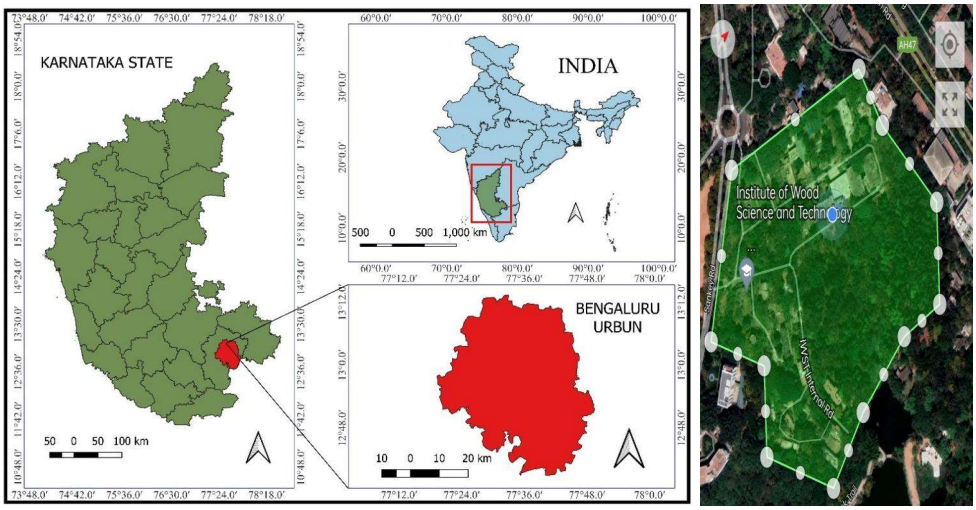

Fig. 1. Sandalwood population in IWST Bengaluru, Karnataka

RESULTS AND DISCUSSION

Variation in leaf size: Wide range of morphological variation were observed in the leaves of the sandalwood for all the parameters (Table 2, 3). The leaf length ranged from 2.50 to 11.50 cm and the breadth from 1.00 to 4.50 cm. Based on leaf size, sandalwood leaves were grouped into three classes, *Viz.,* big (9.0-11.5 cm length; 3.6-4.5 cm breadth), medium (5.0-8.0 cm length; 2.0 to 3.5 cm breadth) and small (2.5-4.0 cm length; 1.0 to 1.7 cm breadth). 60%, 25%, and 15% were medium-sized, smaller-sized and bigger-sized leaf trees were recorded. The LUQW of the standard leaf varies from 0.53 to 2.76 cm, the LDQW varies from 0.64 to 4.12 cm, the LTA varies from 15.93^0 to 69.80^0, LBA varies from 18.72^0 to 86.52^0, PL varies from 0.26 to 1.56 cm, LA varies from 3.43 to 28.84 cm^2, LP varies from 3.59 to 21.74, LT varies from 0.06 to 0.26 mm (Fig. 3).

Variation in leaf shape: 35% were ovate and lanceolate-shaped, and the remaining 30% were elliptic-shaped (Fig. 4 and Table 2, 3).

Variation of leaf phenotypic traits: The big elliptic leaves recorded the highest mean LL and the big lanceolate leaves recorded the highest mean of LMW and PL. The highest mean of LUQW, LDQW, LA, and LP was recorded in the big ovate leaves and the highest mean LTA, LT and LBA was recorded in medium ovate leaves. The mean lowest value of LL was recorded in small ovate leaves, the mean LMW in

Table 2. Leaf phenotypic traits of Sandalwood (Mean ± SD)

Leaf size	Leaf shape	LL	LMW (Breadth)	LUQW	LDQW	LTA	LTT	LBA	LBT
Big	Ovate	9.24±1.05	3.65±0.44	2.76±0.32	4.12±0.50	64.52±4.89	Acute Subacute	82.24±15.95	Equilateral, Round
	Elliptic	10.25±1.35	3.73±0.37	1.77±0.15	3.90±0.27	59.20±11.64	Acute	83.68±15.02	Oblique, Round
	Lanceolate	9.86±0.82	3.76±0.26	1.96±0.22	2.47±0.31	66.28±9.53	Round Mucronate Acute Subacute	66.96±8.72	Equilateral, Acute
Medium	Ovate	5.42±0.73	2.89±0.42	2.50±0.43	3.26±0.48	69.80±12.43	Acute Round Mucronate Obtuse Subacute	86.52±9.68	Equilateral Oblique, Round, Cuneate
	Elliptic	7.26±0.54	2.54±0.20	1.48±0.12	2.64±0.24	58.92±10.31	Acute	72.64±7.57	Equilateral
	Lanceolate	6.20±0.57	3.09±0.25	1.70±0.20	2.10±0.25	60.40±6.38	Acute Subacute	71.00±9.11	Acute
Small	Ovate	2.51±0.53	1.12±0.25	0.93±0.20	1.19±0.24	28.03±5.72	Acute Mucronate Retuse	31.72±6.78	Round, Obtuse
	Elliptic	2.97±0.38	1.04±0.16	0.70±0.13	1.90±0.15	20.94±3.81	Acute	24.36±4.45	Round, Oblique
	Lanceolate	2.55±0.19	1.68±0.09	0.53±0.07	0.64±0.08	15.93±2.05	Acute	18.72±10.97	Acute

Table 3. Leaf phenotypic traits of Sandalwood (Mean ± SD)

Leaf size	Leaf shape	PL	PT	LA	LP	LM	LC	LT	PC	VC
Big	Ovate	0.97±0.20	Straight Twisted	28.84±5.03	21.74±2.25	Entire non-wavy	Green	0.20±0.04	Yellowish green	Yellowish green
	Elliptic	1.26±0.22	Straight Twisted	18.04±4.38	18.94±2.76	Entire non-wavy	Dark green	0.18 ±0.05	Yellowish green	Yellowish green
	Lanceolate	1.56±0.18	Straight Twisted	13.52±2.95	15.66±1.60	Entire wavy	Green	0.14±0.02	Yellowish green	Yellowish green
Medium	Ovate	1.46±0.21	Straight Twisted	17.52±3.88	17.22±1.58	Entire non-wavy	Yellowish green	0.26±0.06	Yellowish green	Yellowish green
	Elliptic	1.12±0.12	Straight Twisted	9.28±1.47	12.30±1.21	Entire wavy	Medium green	0.15±0.06	Yellowish green	Yellowish green
	Lanceolate	1.13±0.33	Straight Twisted	11.54±2.15	14.76±1.44	Entire wavy	Yellowish green	0.17±0.02	Yellowish green	Yellowish green
Small	Ovate	0.44±0.09	Straight Twisted	4.56±1.3	4.14±1.29	Entire wavy	Light green	0.10±0.02	Yellowish green	Yellowish green
	Elliptic	0.35±0.06	Straight Twisted	4.65±0.82	4.69±0.88	Entire non-wavy	Green	0.08±0.02	Yellowish green	Yellowish green
	Lanceolate	0.26±0.03	Straight Twisted	3.43±0.45	3.59±0.46	Entire non-wavy	Yellowish green	0.06±0.01	Yellowish green	Yellowish green

small elliptic leaves, and the lowest mean value of LUQW, LDQW, LTA, LBA, PL, LA, LP, and LT was recorded in small lanceolate leaves (Table 2, 3). The highest L/B was recorded in small and big elliptic leaves and the highest A/P was recorded in big ovate leaves. The lowest value of L/B and A/P was observed in small elliptic and medium lanceolate respectively. One way analysis of variance confirmed that, there is a significant difference among some of the quantitative parameters of leaf phenotypic traits in sandalwood.

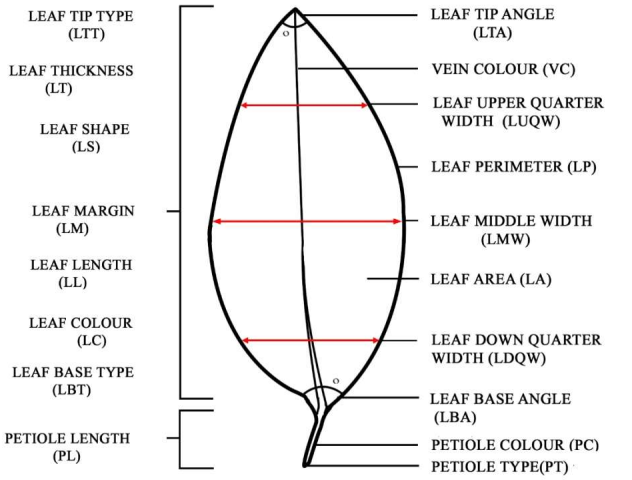

Fig. 2. Diagrammatic representation of leaf parameters of sandalwood

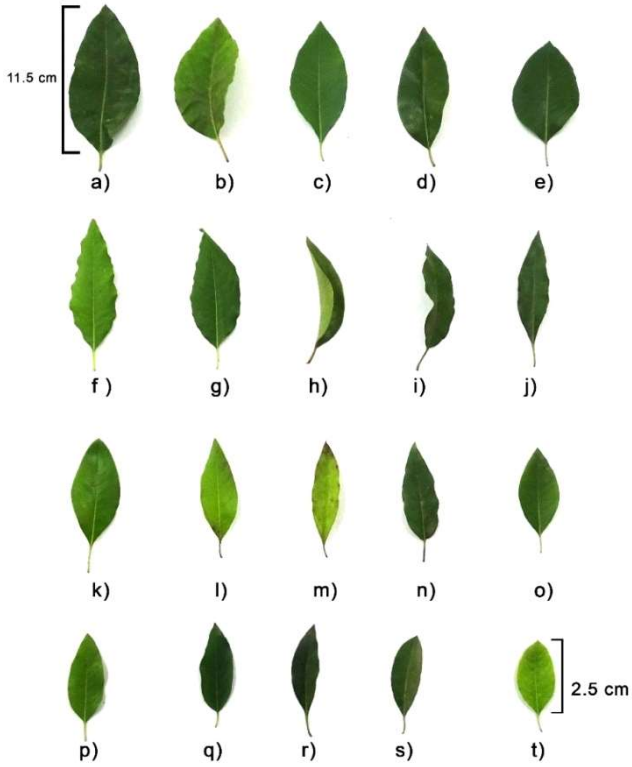

Fig. 3. Classes of sandalwood leaves, big leaves (a-e) medium leaves (f-o), and small leaves (p-t)

Big Ovate (BO): The length/breadth ratio was 2.53, and the leaf area/perimeter ratio of 1.32 was recorded (Fig. 3 b, e).

Big Elliptic (BE): The length/breadth ratio was 2.74, and the leaf area/perimeter ratio of 0.95 was recorded (Fig. 3 a, d).

Big Lanceolate (BL): The length/breadth ratio was 2.62, and the leaf area/perimeter ratio of 0.86 was recorded (Fig. 3 c).

Medium Ovate (MO): The length/breadth ratio was 1.87, and the leaf area/perimeter ratio of 1.01 was recorded (Fig. 3 h, g).

Medium Elliptic (ME): The length/breadth ratio was 2.85, and the leaf area/perimeter ratio of 0.75 was recorded (Fig. 3 f, i, n).

Medium Lanceolate (ML): The length/breadth ratio was 2.00, and the leaf area/perimeter ratio of 0.78 was recorded (Fig. 3 j, k, l, m, o).

Small Ovate (SO): The length/breadth ratio was 2.24, and the leaf area/perimeter ratio of 1.10 was recorded (Fig. 3t).

Small Elliptic (SE): The length/breadth ratio was 2.85, and the leaf area/perimeter ratio of 0.99 was recorded (Fig. 3p, q).

Small Lanceolate (SL): The length/breadth ratio was 1.51, and the leaf area/perimeter ratio of 0.95 was recorded (Fig. 3r, s). Detailed nine phenotypic leaf traits were explained in Tables 2, 3.

Variation in leaf colour: Sandalwood leaf shows distinct colour variation from dark green to yellowish green (Fig. 5).

Variation in tip and base of leaves: A total of six types of variation were observed in both the tip and base of sandalwood leaves. Tip types were Acute, Retuse, Round, Subacute, Obtuse, and Mucronate. Base types are Equilateral, Acute, Cuneate, Round, Obtuse, and Oblique (Fig. 6, 7). All six types of leaf tip were present in ovate leaf, four types of leaf tip (Round, Mucronate, Acute, and Subacute) were recorded in lanceolate and only one type was presented in elliptic (Acute). Five types of leaf bases were present in ovate (Round, Equilateral, Cuneate, Oblique,

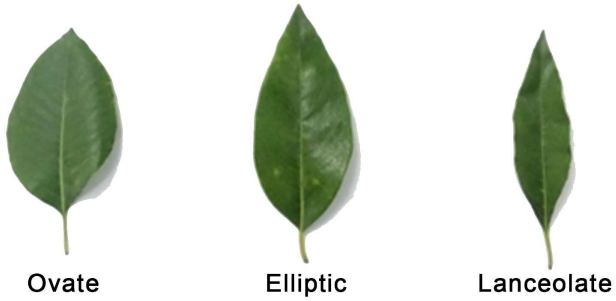

Fig. 4. Variation in leaf shapes of sandalwood

Obtuse), three were in elliptic (Round, Equilateral, Oblique), and two in lanceolate (Equilateral, Acute).

Variation in petiole and margin of leaves: Two types of petioles *Viz.,* straight and twisted were observed. The leaf margin showed wavy and non-wavy types. Both veins and petiole were yellowish-green in colour (Fig. 8, 9).

Correlation among leaf phenotypic traits: The correlation matrix (Pearson) of sandalwood leaf parameters showed a significantly positive correlation (Table 4). The highest correlation (r= 0.96) was between LTA and LBA; the lowest correlation (r= - 0.02) was observed between LBA and A/P. Thus, all leaf parameters were associated positively with each other.

Extent degree of leaf phenotypic traits: The highest CV was recorded in leaf base angle (LBA) (10.42-58.60%) and the lowest in leaf middle width (LMW) (5.36-22.32%.) The coefficient of variation (CV) for all the quantitative traits shown in Table 5.

Unique characteristics feature in leaf traits of sandalwood: Some of the leaves showed unique characteristic feature in their leaves. The apex of the leaf comes inward direction, this type of observation were recorded in medium-sized elliptic leaves (Fig. 3 g) and folded leaves (Fig. 3 h). Some of the small ovate leaves were (margins of the leaf slightly folded inward direction) cup-shaped (Fig. 3 t) and the branches of these trees were a drooping pattern. Small-shaped lanceolate leaves (Fig. 3 m) were also found in dropping branches of sandalwood trees.

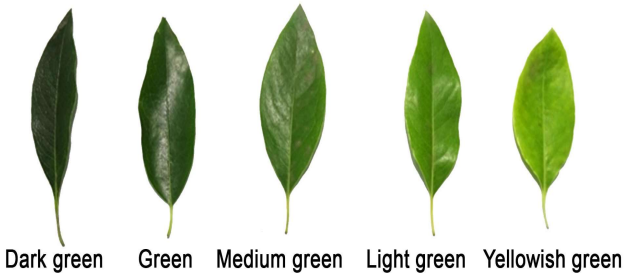

Fig. 5. Colour variation in sandalwood leaves

Table 4. Pearson's correlation matrix among the leaf phenotypic traits

	LL	LMW	LUQW	LDQW	LTA	LBA	PL	LA	LP	LT	L/B	A/P
LL	1											
LMW	0.937792	1										
LUQW	0.723431	0.814578	1									
LDQW	0.810435	0.771937	0.862085	1								
LTA	0.816756	0.883298	0.905624	0.793295	1							
LBA	0.815684	0.871804	0.901077	0.878105	0.969475	1						
PL	0.796597	0.856632	0.78797	0.684421	0.951964	0.893758	1					
LA	0.759738	0.809195	0.931588	0.910574	0.767969	0.820255	0.610624	1				
LP	0.879376	0.935765	0.938618	0.921168	0.922368	0.951816	0.827237	0.933592	1			
LT	0.567908	0.698735	0.912957	0.809332	0.881559	0.920947	0.793978	0.790935	0.860557	1		
L/B	0.491529	0.181495	0.142505	0.467367	0.226803	0.239985	0.216571	0.199161	0.243362	0.018202	1	
A/P	-0.03572	-0.03713	0.310077	0.293106	-0.09547	-0.02228	-0.27121	0.490281	0.158355	0.143907	0.03719	1

Correlation is significant at a 0.05 probability level

Table 5. Coefficient of variation in leaf phenotypic traits (%)

CV	LL	LMW	LUQW	LDQW	LTA	LBA	PL	LA	LP	LT
BO	11.36	12.05	11.59	12.14	7.58	19.39	20.62	17.44	10.35	20.00
BL	13.17	9.92	8.47	6.92	19.66	17.95	17.46	24.28	14.57	27.78
BE	8.32	6.91	11.22	12.55	14.38	13.02	11.54	21.82	10.22	14.29
MO	13.47	14.53	17.20	14.72	17.81	11.19	14.38	22.15	9.18	23.08
ML	7.44	7.87	8.11	9.09	17.50	10.42	10.71	15.84	9.84	40.00
ME	9.19	8.09	11.76	11.90	10.56	12.83	29.20	18.63	9.76	11.76
SO	21.12	22.32	21.51	20.17	20.41	21.37	20.45	28.51	31.16	20.00
SL	12.79	15.38	16.46	7.89	18.19	18.27	17.14	17.63	18.76	25.00
SE	7.45	5.36	13.21	12.50	12.87	58.60	11.54	13.12	12.81	16.67

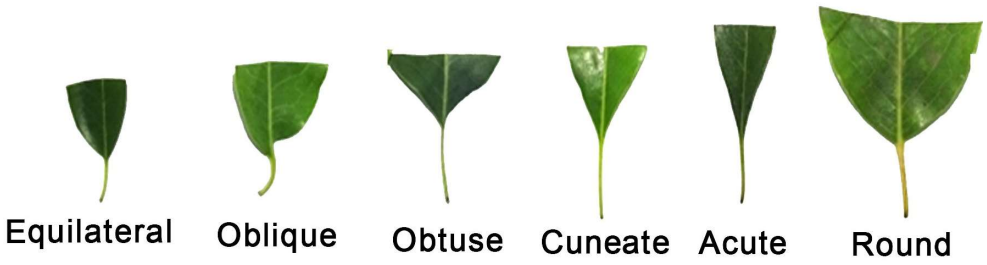

Fig. 6. Variation in leaf base of sandalwood

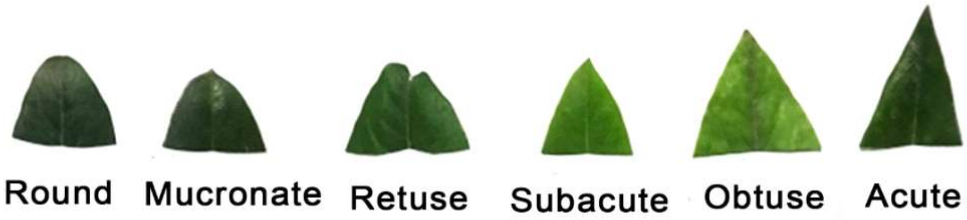

Fig. 7. Variation in leaf tip of sandalwood

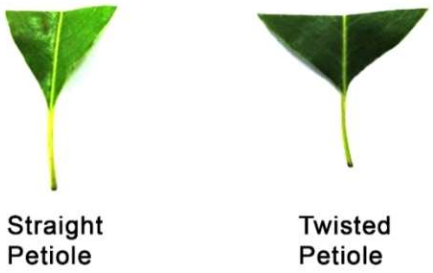

Fig. 8. Variation in leaf petioles of sandalwood

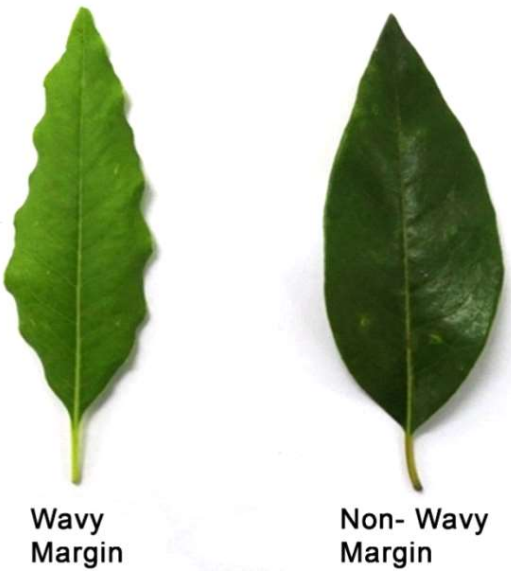

Fig. 9. Variation in leaf margin of sandalwood

The taxonomic importance of leaf variation is reported in several tree species namely *Populus simonii* and *P. nigra* (Jingshan Ren et al 2020), *Pyrus pyraster* (Antonio et al 2022) and *Carpinus tschonoskii* (Runan et al 2022). In general, leaf morphology characteristics can be varied between species, different populations of the same species, or within an individual at different development stages. It has been considered that leaf size is influenced by environmental as well as genetic factors (Hay and Tsiantis 2006). But when it comes to sandalwood leaf diversity did not exhibit any correlation with geographical locations or climate (Kulkarni and Srimathi 1998). The occurrence of intermixed types in a forest account for polygenic inheritance. The segregation of these types was also observed in the progeny trials showing a heterogeneous nature of the species. Similar findings were recorded by Kulkarni (1995) categorized sandalwood leaves into six biotypes *Viz.*, (1) ovate (2) elliptic (3) lanceolate (4) linear (5) big and (6) small. In the ovate biotype two sub-types *Viz.,* (a) ovate -lanceolate (b) ovate-elliptic were found with similarities in leaf length, breadth (width), length/breadth ratio and leaf area (De Candolle 1857).

CONCLUSION

In the *Santalum album,* L. leaves were categorized into nine types based on phenotypic traits, mainly on their variation in size and shape, such as big ovate, big lanceolate, big elliptic, medium ovate, medium lanceolate, medium elliptic, small ovate, small lanceolate and small elliptic. In each leaf category, studied the twenty leaf parameters such as LL, LMW, LUQW, LDQW, LTA, LTT, LBA, LBT, PL, PT, LA, LP, LM, LS, LC, LT, PC, VC, A/P, and L/B. The variation in sandalwood trees can be utilized the selection and improvement of superior genotypes. Leaf parameters were

very useful for better understanding of the sandalwood phenotypic variation at the taxonomic level. IWST, Bengaluru is conserving phenotypically diverse sandalwood population, that can be further utilized for tree improvement programmes.

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Detection of Plastid-based SNPs to Resolve *Bambusa tulda-longispiculata-nutans-teres* Complex in Bamboo Taxonomy

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***Abstract*:** The SNP barcodes are a viable option for identifying cultivars or species, hence to find single nucleotide polymorphisms (SNPs) that can distinguish the *Bambusa tulda-longispiculata-nutans-teres* complex, the plastid genes *rbcL* (ribulose bi-phosphate carboxylase), *matK* (maturase K), and *rpoC1* (RNA polymerase C1) were targeted. Through amplification of these plastid genes and sequencing of amplicons, alignment, and mining of the sequence, SNPs were discovered using NovoSNP software. Over 2045 bp sequenced plastid DNA, seven SNPs were identified in targeted three barcode genes. Three SNPs were found in the *matK* gene, which was of 868 bp length, whereas two SNPs were found in each of the *rbcL* gene's 730 bp and *rpoC1*'s 447 bp lengths. Based on that, discovered that *B. nutans* differed from all other species in terms of SNPs present in the *rbcL* and *rpoC1* genes, but *B. longispiculata* was determined to be distinct from all three species with respect to SNPs present in the *matK* gene. Out of seven identified SNPs, the unique heterozygous nucleotide A/G at locus 520G/A and the nucleotide 'C' at locus 713 bp were observed in *Bambusa longispiculata,* which were absent in all the other three species. These identified SNPs can be utilized to differentiate these taxonomically closely related bamboo species.

***Keywords*:** Amplification, Bamboo complex, Plastid genes, Sequencing, SNP discovery

Bamboo is a woody perennial grass that belongs to the subfamily Bambusoideae within the family Poaceae. It is one of the fastest growing plants (Singh et al 2022). It exhibits 70 genera and more than 1200 species worldwide (Dajun and Shao-Jin 1987). Based on flowering, 67 genera of woody bamboos have been placed in the nine sub-tribes (Dransfield and Widjaja 1995 and Li 1997). India is the second-largest reservoir of bamboos with a total of 136 bamboo species belonging to 23 genera (Hauchhum and Singson 2019). Most bamboo species flower once in a lifetime and then die. Its flowering time is uncertain and varies from 1 year to 120 years, depending on the species. The uncertainty in flowering of bamboo species makes it very difficult to identify closely related bamboo species taxonomically based on morphological characters. The taxonomic identification of bamboo species based on their morphological characteristics is limited as these characters are highly influenced by environmental factors. Gao et al (2016) suggested that SNP barcodes are highly reproducible, high-throughput, and a good choice for cultivar or species identification. Therefore, it is needed to develop species-specific molecular markers to distinguish bamboo species at the genomic level. Lots of work related to genetic diversity, genetic structure, and phylogenetic relationships among bamboo species has been carried out using various molecular marker systems, v*iz.,* RFLP, ISSR, SSR, AFLP, and SCAR (Nayak and Rout 2005, Barkley et al 2005, Bhattacharya et al 2006, Sun et al 2006, Das et al 2007, Lin et al 2009). However, reports on SNP discoveries that can assist in the taxonomic classification of bamboo species are scant. Therefore, the present study was carried out to discover the SNPs in the plastid genome of the *Bambusa tulda-longispiculata-nutans-teres* complex through the amplification and sequencing of the plastid genes viz. *rbcL, matK,* and *rpoC1*. The obtained SNPs can be utilized as molecular tools for taxonomic identification of these bamboo species.

MATERIAL AND METHODS

Sample collection: To carry out the study, seven samples of *Bambusa tulda* (BT), nine samples of *Bambusa nutans* (BN), and one sample each of *Bambusa teres* (BTE) and *Bambusa longispiculata* (BL) were utilized. These samples were collected from different geographical locations in the country (Table 1).

DNA extraction and quantification: Total genomic DNA was extracted and purified from the young leaves of bamboo as per Vinod (2004). The quality and quantity of extracted genomic DNA were assessed using a bio photometer and gel electrophoresis, respectively. The UV-based bio photometer plus was used to measure the optical density (OD) of DNA samples at 260 nm and 280 nm, and the A_{260}:A_{280} ratio was

worked out for the purity index. Simultaneously, DNA samples were electrophoresed in 0.8% agarose gel (XcelGen®, #XGA) at a constant voltage of 80 V with 0.05 LmL-1 (stock-10 mg mL^{-1}) ethidium bromide (Himedia®, #MB071) in 0.5X TBE (Tris, boric acid, and EDTA) buffer for 1 h.

Amplification of plastid-based candidate genes: The pre-designed universal primers (Table 2) for *rbcL* (ribulose bi-phosphate carboxylase), *matK* (maturase K), and *rpoC1* (RNA polymerase C1) genes were synthesized through Xcelris Labs Ltd. and subjected to amplify the selected candidate genes in a panel of four bamboo species using gradient PCR and a basic PCR. A 20 µL reaction mixture was prepared by adding 50 ng of template DNA, 0.2 µM of each primer (Xcelris), 0.2 mM of dNTPs (Fermentas®, #R0192), 2.5 mM of $MgCl_2$(ThermoFisher #AB0359), and 2U Taq DNA polymerase (ThermoFisher #EP0712) with 1X green buffer (ThermoFisher), and the mixture was subjected to amplify in the gradient PCR at 94 °C for 5 minutes for initial denaturation, followed by denaturation, annealing, and extension for 35 cycles at 94 °C for 45 seconds, 49-60°C for 30 seconds at a gradient of 1°C for 45 seconds, 49-60°C for 30 seconds at a gradient of 1°C for 1 minute, and the final extension was performed at 72°C for 5 minutes. After optimization, a 50 µL reaction mixture was prepared by adding the chemicals at the above concentration, and the mixture was subjected to PCR amplification at 94 °C for 5 minutes, followed by a three-step cycle of denaturing at 94 °C for 4 seconds, annealing at 48 °C for *rbcL* and 53 °C for *matK* and *rpoC1* for 30 seconds, and extension at 72 °C for 1 minute. The cycle was repeated 35 times before a final

Table 2. PCR primers used for amplification of bamboo species

Primer	Sequence	T_m (°C)	T_a (°C)
rbcL 1F	ATGTCACCACAAACAGAAAC	56	48
rbcL724 R	TCGCATGTACCTGCAGTAGC	66	48
matK X F	TAATTTACGATCAATTCATTC	52	53
matK 5 R	GTTCTAGCACAAGAAAGTCG	58	53
rpoC1-2 F	GGCAAAGAGGGAAGATTTCG	68	53
rpoC1-3 R	TGAGAAAACATAAGTAAACGGGC	64	53

Table 1. Collection of Bamboo samples from wide geographical locations in Jharkhand and West Bengal for DNA extraction and SNP discovery

Plant code	Location	latitude	longitude	Elevation	Humidity/ Rain fall
Bambusa tulda					
BT-1	Jalpaiguri, WB	26.5215° N	88.7196° E	89 m	63% humidity, 3242 mm
BT-13	Lalgutwa, Ranchi, JH	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
BT-3	Lalgutwa, Ranchi, JH	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
BT-5	Lalgutwa, Ranchi, JH	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
BT-6	Jalpaiguri, WB	26.5215° N	88.7196° E	89 m	63% humidity, 3242 mm
BT-7	Lalgutwa, Ranchi, JH	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
BT-9	Lalgutwa, Ranchi, JH	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
Bambusa nutans					
BN-9	Sukna, Siliguri, Darjeling	26.6841 ° N	88.3506 °E	5120 m	68% humidity, 3047 mm
BN-4	Jagarnathpur, Mahulia, Ghatsila	22.6338° N	86.4342°E	103 m	85% humidity, 1241 mm
BN-10	Jamuney, Daltonganj	24.0465° N	84.0768°E	215 m	1174 mm,, 79% humidity
BN-11	Sukna, Siliguri, Darjeling	26.6841 ° N	88.3506 °E	5120 m	68% humidity, 3047 mm
BN-13	Sukna, Siliguri, Darjeling	26.6841 ° N	88.3506 °E	5120 m	68% humidity, 3047 mm
BN-15	Sukna, Siliguri, Darjeling	26.6841 ° N	88.3506 °E	5120 m	68% humidity, 3047 mm
BN-3	Kakrisol, Chakulia	22.4737° N	86.7465° E	115 m	83% humidity, 1294 mm
BN-5	Lalgutwa, Ranchi	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
BN-7	Lalgutwa, Ranchi	23.3441° N	85.3096° E	651 m	56% humidity, 1430 mm
Bambusa teres					
BTE	BSI, Kolkata	22.5726° N	88.3639° E	9.14 m	90% humidity 1582 mm
Bambusa longispiculata					
BL	Assam, Jorhat	26.7509	94.2037	116 m	95% humidity, 2244 mm

BT = Bambusa tulda, BN = Bambusa nutans, BTE = Bambusa teres, BL = Bambusa longispiculata

extension at 72 °C for 5 minutes. The amplified PCR products were electrophoresed for 90 minutes on 1.5% agarose (XcelGen®, #XGA), containing 0.5 μgmL^{-1} ethidium bromide (Himedia®, #MB071), at 80 V.

DNA sequencing and SNP discovery: The single prominent band obtained through *rbcL*, *matK,* and *rpoC1* primers in a set of bamboo germplasm was subjected to sequence by the di-deoxy chain termination method in an automated DNA sequencer (3500 Genetic Analyzer of AB applied biosystem) through Sanger's method. The obtained sequenced data was blasted against the NR (non-redundant) data base in NCBI (https://www.ncbi.nlm.nih.gov/) to find the similarity and identity of the amplified product. The sequenced data of the *rbcL, matK, and rpoC1* genes were aligned separately, and SNPs were searched through NovoSNP software (Weckx et al. 2005). The species-wise SNP table was generated to find the species-specific SNPs to resolve the bamboo taxonomy of four closely related bamboo species, *viz., Bambusa tulda-longispiculata-nutans-teres* complexes. The images of gel electrophoresis amplicons were processed through the programme Gene System. The size or weight of the amplicons was determined using the programme Alpha Ease 4.0. The sequenced data of each gene was validated manually on Finch TV, and the noisy peak at both ends of the nucleotide was trimmed and saved. The forward and reverse sequence reads of a gene were combined in the Bioedit programme and a gene contig was prepared. Sequenced data of a gene from all accessions were individually aligned in Cluster W and the Bioedit software (Fig. 1), and SNPs were discovered at a species level through NovoSNP software. The discovered SNPs were used to generate a phylogenetic tree by applying a maximum likelihood model with 600 bootstrap values in MEGA 7 software.

RESULTS AND DISCUSSION

In the present study, SNPs were searched under plastid barcode genes using NovoSNP software to find species-specific SNPs that could distinguish four bamboo species in *Bambusa tulda-longispiculata-nutans-teres* complexes. The 900 bp, 750 bp, and 500 bp long plastid-based *matK*, *rbcl,* and *rpoC1* genes were amplified in collected accessions of these bamboo species. The amplified amplicons were sequenced and blasted against the data base in NCBI. The eighteen accessions of four bamboo species showed 100% sequencing success, with a robust sequencing peak (Fig. 2). The BLAST result revealed that the *matK* gene of size 901 bp showed 100% query cover, a 0.0 E-value, and 99.89% identity with the *matK* gene of other bamboo species. The *rbcL* gene of size 730 bp showed 100% query cover, a 0.0 E-value, and 99.45% identity with the *rbcL* gene of *Bambusa variostriata* and other species. The *rpoC1* gene of size 445 bp showed 100% query cover, a 0.0 E-value, and 99.10% identity with the *rpoC1* gene of other bamboo species. The sequence results of *all three target* genes were aligned separately, and SNPs were searched. *A total* of seven SNPs were detected in the three genes covering 2045 bp of plastid DNA. The *matK* gene of size 868 bp showed three SNPs (Table 3), whereas the *rbcL* gene of size 730 bp and the *rpoC1* gene of size 447 bp showed two SNPs each (Table 4, 5). The *matK* gene of size 868 bp showed three SNPs where, at locus 520A/G, the base G (guanine) was predominantly present in BTE, BN, and BT, and heterozygous base A/G was present in BL. Similarly, at locus 700T/C, the base T

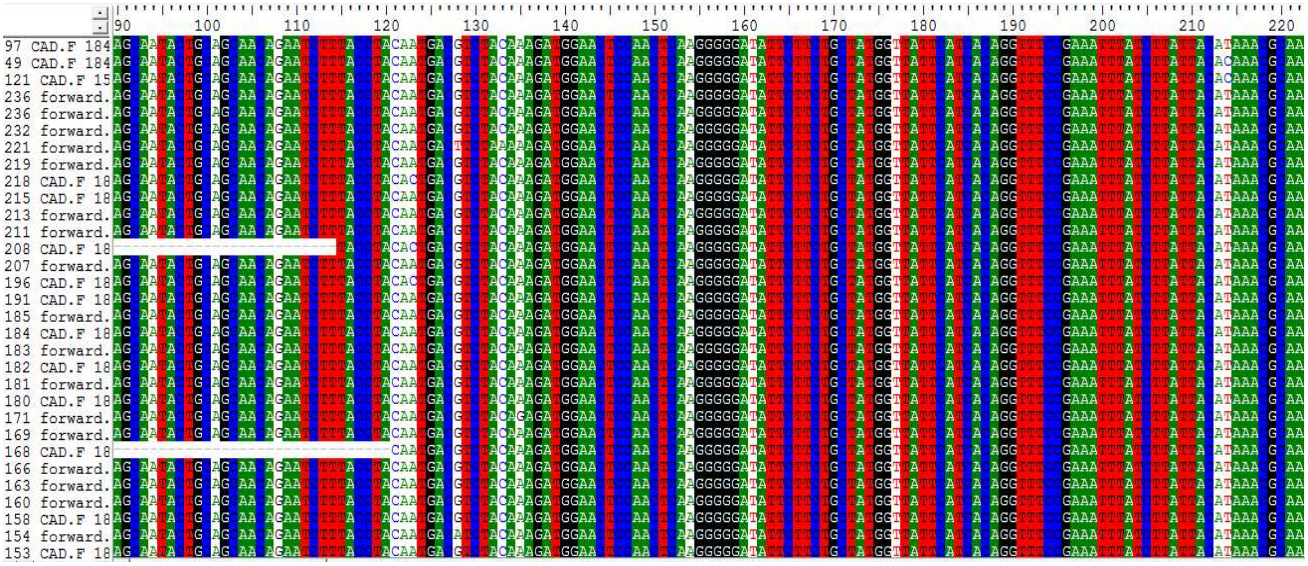

Fig. 1. Alignment of sequenced data in Bioedit software

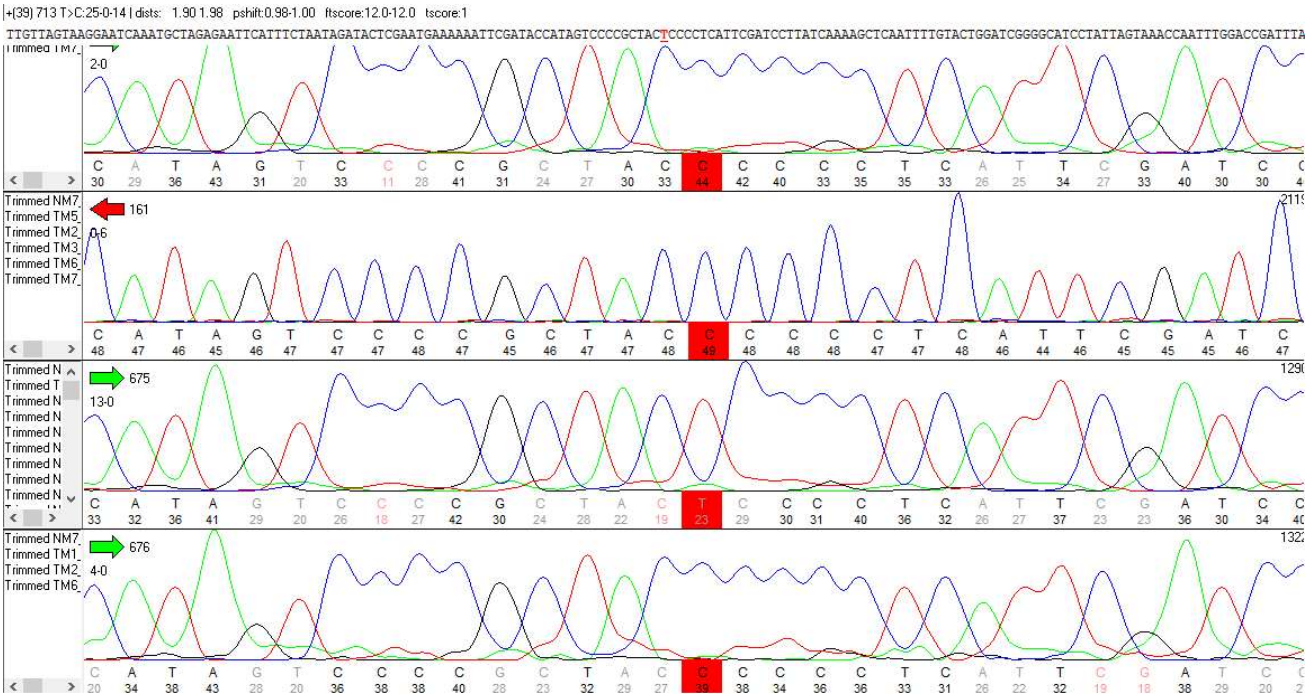

Fig. 2. Aligned peak of sequenced data in NovoSNP software. The nucleotide with red mark showed single nucleotide polymorphism

Table 3. SNPs present in 868 bp long *matK* gene in studied bamboo species

Bamboo species	No. of accessions	Read no. (Replication)	Identified SNPs		
			Loci 520	Loci 700	Loci 713
B. teres	1	4	G	T	T
B. longispiculata	1	4	A/G	C	C
B. nutans	9	25	G	T	T
B. tulda	7	14	G	T	C (1T)

Table 4. SNPs present in 730 bp long *rbcL* gene in studied bamboo species

Bamboo species	No. of accessions	Read no. (replication)	Identified SNPs	
			Loci 418A/C	Loci 667C/A
B. teres	1	4	A	C
B. longispiculata	1	4	A	C
B. nutans	9	38	5C, 4A	5A, 4C
B. tulda	7	36	7A	7C

Table 5. SNPs present in 447 bp long *rpoC1* gene in the studied bamboo species

Bamboo species	No. of accessions	Read no. (replication)	Identified SNPs	
			Loci 32A/G	Loci 77 A/G
B. teres	1	4	A	C
B. longispiculata	1	4	A	C
B. nutans	9	14	4A, 5A/G	5A, 4A/G
B. tulda	7	18	7A	7A

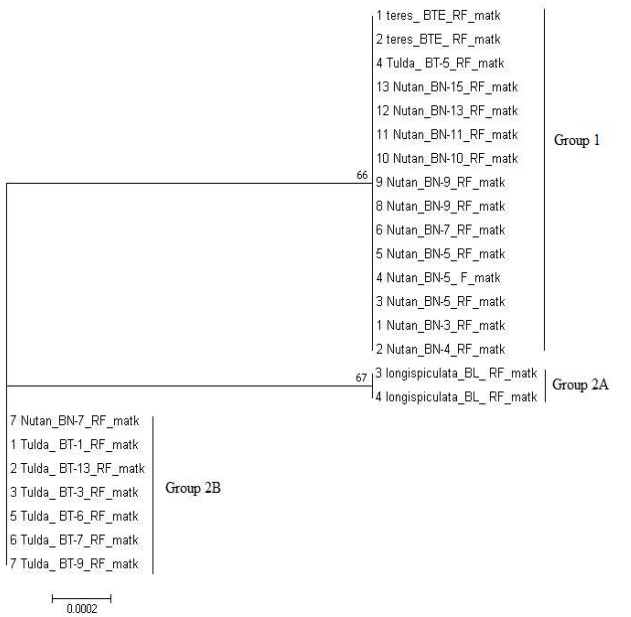

Fig. 3. Phylogenetic tree generated using SNPs variation identified under *matK* gene in four bamboo species

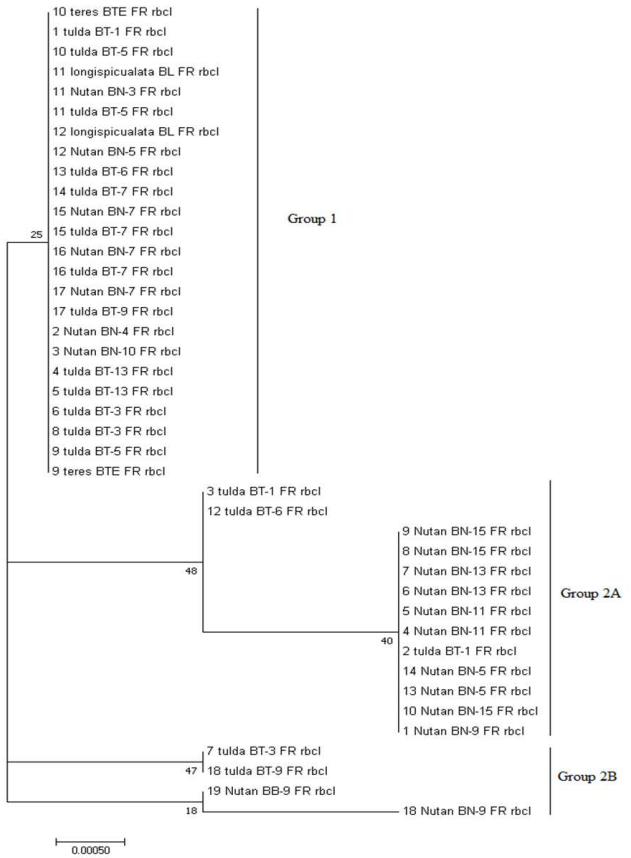

Fig. 4. Phylogenetic tree generated using SNPs variation identified under *rbcL* gene in four bamboo species

(thymine) was predominantly present in BTE, BN, and BT, and the base C was present in BL. In the case of locus 713T/C, the base T was present in BTE and BN, whereas the base C (cytosine) was predominantly present in BT and BL, respectively. The *rbcL* gene of size 730 bp showed two SNPs at locus 418A/C: base A was present in BTE, BL, BT, and BN, whereas base 'C' was only present in a few accessions of BN. Similarly, at locus 667C/A, the base C was predominantly present in BTE, BL, and BT. In BN, base A was present in five studied accessions and base C in four accessions at locus 667C/A. The *rpoC1* gene of size 447 bp showed two SNPs: at locus 32A/G, base 'A' was present in BTE, BL, BT, and BN, whereas a heterozygous base A/G was predominantly present in BN. Similarly, at locus 77A/G, the base 'A' was present in BTE, BL, BT, and BN, and a heterozygous base A/G was present in BN alone.

Based on detected seven SNPs, *B. longispiculata* was found to be different from all three species with respect to SNPs present in the matK gene (Fig. 3), whereas *B. nutans* was found to be different from all other species with respect to SNPs present in the *rbcL* and *rpoC1* genes (Fig. 4, 5). Out of seven identified SNPs, the unique heterozygous nucleotide A/G at locus 520G/A and the nucleotide 'C' at locus 713 bp were observed in *Bambusa longispiculata,* which were absent in all the other three species. In wheat, Gao et al. (2016) selected 43 SNPs from an array of 9000 SNPs that help in discriminating different varieties of wheat. Similarly, in capsicum, SNPs derived from nuclear and cytoplasmic DNA were used for taxonomic classification of distinct species of capsicum (Jeong et al. 2010). In bamboo, this is perhaps the first effort to identify SNPs to differentiate these closely related four species.

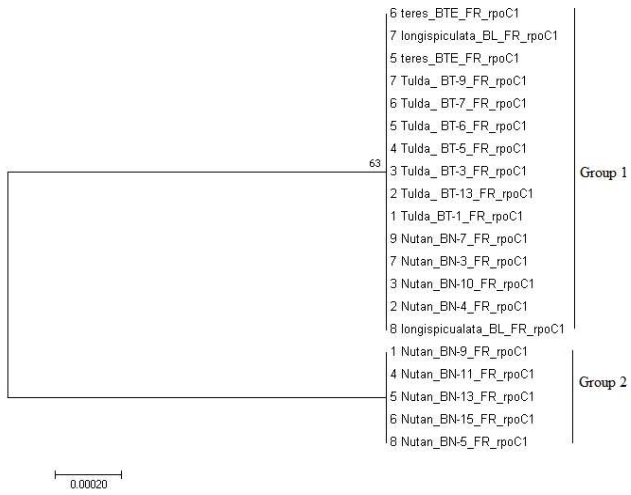

Fig. 5. Phylogenetic tree generated using SNPs variation identified under *rpoC1* gene in four bamboo species

CONCLUSION

The study demonstrates that the taxonomically closed *Bambusa tulda-longispiculata-nutans-teres* complex can be distinguished through single nucleotide polymorphism (SNP) discovery using plastid genes, i.e., *rbcL* (ribulose bi-phosphate carboxylase), *matK* (maturase K), and *rpoC1* (RNA polymerase C1). The SNPs detected in the *matK* gene can differentiate *B. longispiculata* from the other three species, whereas the SNPs detected in the *rbcL* and *rpoC1* genes can differentiate *B. nutans* from the other three species. These species-specific SNPs need to be validated in a large set of germplasm.

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Herbaceous Species Diversity and Temporal Change in Biodiversity Heritage Site of GKVK, Bengaluru Campus

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***Abstract*:** The biodiversity heritage site of GKVK in Bengaluru was assessed for its herbaceous species composition, diversity and structure to better understand the seasonal vegetation dynamics and to provide baseline data for future conservation. A total of 600 quadrats (1 m x 1 m) in summer and winter season were established using random quadrat sampling method for vegetation sampling. A total of 59 species belonging to 55 genera and 25 families were recorded in winter and 39 species belonging to 36 genera and 14 families in summer season. The study site was dominated by the individuals of *Cynodon dactylon* (IVI=20.96) in summer season and *Panicum maximum* (IVI=26.25) in winter season. Shannon diversity index (3.12 and 3.30) and Simpson diversity index (0.94, 0.95) varied between summer and winter season, respectively. Herbaceous species diversity varied greatly between different seasons and different land use systems. Agricultural land use system had the greatest number of species with 35 and 39 species followed by planted Forest with 15 and 28 species in summer and winter season, respectively. Natural forest ecosystem had the least number of species compared to other land use systems. The present study hints at the influence of changes in land use pattern around the natural ecosystem and the work will provide baseline data for future conservation and management practices in the study area.

***Keywords*:** Biodiversity, Heritage site, Land use systems, Conservation

The global biodiversity crisis has given rise to a growing concern at the prospect of a rapidly accelerating loss of species, population, domesticated varieties, medicinal herbs and natural habitats (Shameem et al 2010). Herbaceous plants represent a significant proportion of the biodiversity, but they remain largely understudied despite their ecological relevance: they contribute to ecological processes, serve as ecological indicators of habitat quality and provide food and shelter for numerous wildlife species (Jones et al 2014, Willie et al 2014). Herbs can be classified as generalists which occur in all habitat types. The species diversity and composition of herbaceous plant communities can vary depending on habitat settings. Forest canopies either promote the growth of ground vegetation or hinder it by competition. Each landscape element is subjected to specific disturbances by management such as cultivation, trampling and mowing as well as abandonment (Kitazawa and Ohsawa 2001). Herbaceous vegetation can be affected by natural and anthropogenic disturbances including individual tree falls, catastrophic wind events, catastrophic fire, and timber harvesting that increase light and expose mineral soil (Elliott et al 2011, Belote et al 2012).

Various habitats can be regarded as spatially and temporally dynamic patches of vegetation being subjected to diverse human interference (Bhuju and Ohsawa 2001). Stability and vulnerability of ecosystems depend on species diversity that is defined by the spatio-temporal alteration in species composition and their distribution (Gillet et al 1999). Herbaceous plant species diversity and composition are affected by tree stand structure, tree species composition and topographic and environmental variables (Jones et al 2014, Akhtar and Bergmeier 2015). Tree canopies play a critical role in the spatio-temporal build-up of herbaceous species diversity and production (Sanchez-Jardon et al 2010). Understanding the composition, distribution, and diversity of herbaceous vegetation is basic to the understanding of dynamics of the forest ecosystem (Sagar et al 2012). Studies on herbaceous plant abundance, distribution, diversity and composition in forest stands at different successional stages can inform biodiversity conservation policy and forest management practices (Fraser et al 2014, Willie 2014).

Biodiversity heritage site of GKVK campus is a semi-natural and agricultural landscape which is one of the best sites to assess species diversity at a landscape level containing multiple type of habitats or ecosystems such as agricultural fields, plantations, natural forests etc. Floristic diversity of the campus is decreasing because of the increased anthropogenic activities such as agriculture and research in the campus. Therefore, it is necessary to study

and analyse the species richness and diversity to conserve and manage biodiversity in semi-natural ecosystems.The objectives of the present study are to analyse the floristic diversity of the herbaceous species under different land use systems and to find out the temporal change in the herbaceous species diversity and population structure.

MATERIAL AND METHODS

Description of the Study Area and Climate

Study area: The study was carried out in the biodiversity heritage site of Gandhi Krishi Vigyana Kendra (GKVK), UAS Bangalore. 167 hectares of the total area of the campus in 14 patches has been designated as biodiversity heritage site and these 14 patches are named as area A, B, C, D, E1, E2, E3, E4, E5, E6, E7, E8, E9 and E10 which are spread across the campus (Fig. 1). The study area consists of agricultural lands, Natural scrub forests and Planted forests.

Climate: GKVK is situated at an altitude of 924 meters above the mean sea level. The annual rainfall ranges from 528 mm to 1374.4 mm with the mean of 915.5 mm. The temperature and rainfall data will be collected between June 2020 to June 2021 from UAS Bangalore Agrometeorology climate database. The study area is characterized by an average temperature and rainfall of 23.32 °C and 973mm, respectively during the study period (Fig. 2).

Sampling design and vegetation data collection: Random quadrat sampling method was used to study the herbaceous species composition and species diversity. Quadrats of 1 m^2 ware laid in different locations of the study area. Each 1 m^2 quadrat was further divided into four 250 × 250 cm^2 sub-quadrats, as workable units for the study of the herbaceous vegetation. In each quadrat all the species present were identified and individuals counted. The study was carried out for two seasons i.e., summer and winter seasons. A total of 600 quadrats in two seasons were laid in the study site for recording the herbaceous species diversity. Identification of the species was done with the help of local floras and comparing the voucher specimen with the collection in the herbarium, Mahatma Gandhi Botanical Garden, UAS, GKVK, Bengaluru.

Data Analysis

Floristic composition and species diversity: Vegetation data were compiled and summarized using Microsoft Excel 2019. Shannon diversity index (*H´*) and Simpson diversity index (1-D) were determined using $H' = -\sum^{N}_{i=1} P_i \ln P_i$, $D=\sum n_i (ni-1)/N(N-1)$ (where, n_i= Number of individuals of the i^{th} species, N= Total number of individuals, $p_i = n_i/N$), respectively. The Shannon diversity index is a commonly used measure of diversity and it assumes individuals are randomly sampled from an infinitely large population and all the species from a community are included in the sample (Yemata and Haregewoien 2022).

The Hutcheson t-test is a modified version of the classic t-test that provides a way to compare two samples. The Hutcheson t-test was developed as a method to compare the diversity of two community samples using the Shannon diversity index (Hutcheson 1970). The basic formula is similar in appearance to the classic t-test formula, $t = H'_a - H'_b/\sqrt{\text{variance of } H'_a + \text{variance of } H'_b}$ (Where, *H'*=Shannon diversity index for each of the two samples (subscripted a and b). In the present study we used Hutcheson t-test to analyse and compare the diversity of different land use systems.

Population structure: The structure of the community was analysed in terms of density, frequency and importance value index of all herbaceous plant species. The analysis was carried out using Microsoft Excel 2019. Density refers to the number of all individual plants of a species per unit area and Frequency is the probability or the probability of finding a

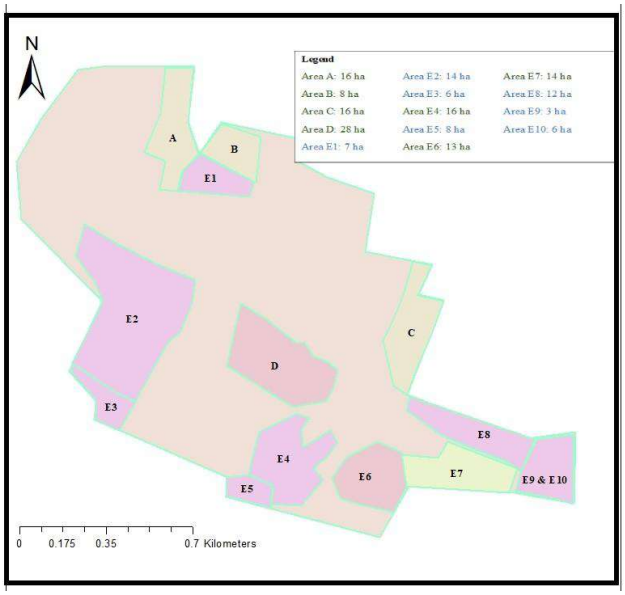

Fig. 1. Map of the study area

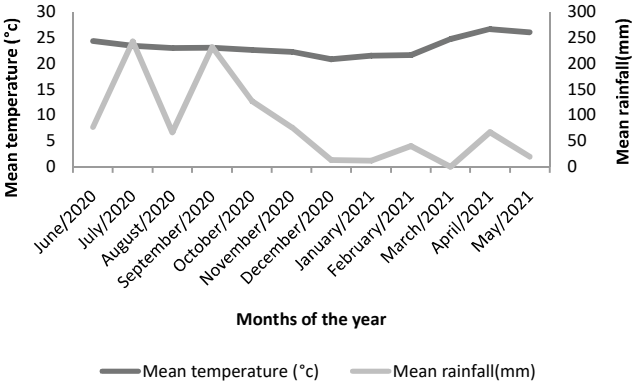

Fig. 2. Rainfall and temperature pattern in the study area during the study period

species in any given quadrat. The frequency value obtained reflects the pattern of distribution.

Relative Frequency and Relative Density were calculated using the formula,

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

$$\text{Relative Density (RD)} = \frac{\text{Number of quadrats in which species is studied}}{\text{Total number of quadrats studied}} \times 100$$

Importance value index (IVI) is an important indicator for the ecological significance of a species. It often reflects the extent of dominance, occurrence and abundance of a given species in relation to other associated species in an area (Kent and Coker 1992). For calculating the IVI of herbaceous species, we use the formula, IVI = RD + RF.

RESULTS AND DISCUSSION

Vegetation composition: A total of 59 species belonging to 55 genera and 25 families were recorded in the winter season and 39 species belonging to 36 genera and 14 families were recorded in summer season (Table 1). Herbaceous species number in the present study was higher than the species richness reported by Mirza and Patil (2021) in Gautala Forest. The number herbaceous species recorded in the GKVK campus is lower than the number of species reported by Suresh and Harish (2000) in Indian Institute of Science, Bangalore campus. This may be attributed to the higher level of anthropogenic disturbance in the study area due to increasing agricultural activities. The occurrence of lower number of species in summer can be attributed to the less availability of the moisture and can also be attributed to ploughing activities which starts at the beginning of summer season. 74.36 and 59.32% of the total floristic composition in summer and winter season, respectively was represented by members of four families. In summer season, Poaceaehad 12 species (30.77%), Asteraceae had 9 species (23.08%), Fabaceae 5 species (12.82%) and Amaranthaceae 3 species (7.69%). In winter season Poaceae had species 16 (27.12%), Fabaceae had 8 species (13.56%), Asteraceae had 6 species (10.17%) and Asteraceae had 5 species (8.47%). This shows that Poaceae was the most dominant family in the study site irrespective of seasons. The success of the family might be result of the presence of a greater number of species and higher adaptation capabilities to varying climate and anthropogenic activities. Among the recorded plants, some are fodder species, such as *Panicum maximum* and *Digitaria ciliaris*. The presence of invasive weed species like *Parthenium hysterophorus* and *Cynodon dactylon* shows that the study ecosystem has been invaded and a further spread of these invaders should be prevented to protect other valuable medicinal and fodder species.

Species diversity: A diverse ecosystem has higher Shannon-Wiener index value, while an ecosystem with a low value will have low species diversity (Deka et al 2012). Shannon diversity index and Simpson diversity index values varied between summer and winter season. 3.12 and 0.94 in summer and 3.30 and 0.95 in winter season, respectively (Table 2) indicating that the study site is a biologically species diverse system with balanced species distribution. The outcomes of the present study show that the study site contains high diversity of herbaceous species both in terms of composition and life forms. The study results show that species diversity was higher in winter season compared to summer.

Different land use systems and floristic diversity: Herbaceous species diversity varied greatly between different seasons and different land use systems. Agricultural land use system had the greatest number of species with 35 and 39 species in summer and winter season, respectively followed by planted forest with 15 and 28 species in summer and winter season, respectively. Each landscape element is subjected to specific disturbances by management such as cultivation, trampling and mowing as well as abandonment: Various management regimes related to agricultural practice led to maintenance of diverse plant communities of different successional stages (Kitazawa and Ohsawa 2001). Natural forest ecosystem had least number of species compared to other land use systems with only 7 and 20 species in summer and winter season, respectively. The different land use systems led to the differences in herbaceous species composition and diversity. Most of the species in cultivated and managed sites were common seasonal weeds.

In summer season, Shannon diversity index and Simpson diversity index values varied between land use systems. According to diversity indices, agriculture land use system (H'=2.68, 1-D=0.90) was the most diverse system fallowed by planted forests (H' =2.27, 1-D=0.87). Least diverse was the natural forests (H'=1.65, 1-D=0.79). Herbaceous species diversity analysis showed a similar trend in winter season with Agriculture land use system (H'=2.76, 1-D=0.90) being the most diverse system fallowed by planted forests (H'=2.62, 1-D=0.89) and the natural forests (H'=1.87, 1-D=0.73). The higher diversity in the agricultural land use system may be attributed to the availability of more nutrients and moisture due to the agricultural operations carried out throughout the year in the study site. Diversity indices values in all type of land use systems were higher in winter season compared to summer in all the land use systems (Table 3). Hutcheson t-test analysis shows that there was significant

Table 1. Herbaceous species composition in the study site

Winter season		Summer season	
Name of the species	Family	Name of the species	Family
Acanthospermum australe (Loefl.) Kuntze.	Asteraceae	*Acanthospermum australe* (Loefl.) Kuntze	Asteraceae
Achyranthes aspera L.	Amaranthaceae	*Acanthospermum hispidum* DC.	Asteraceae
Ageratum conyzoides L.	Asteraceae	*Achyranthes aspera* L.	Amaranthaceae
Alternanthera brasiliana (L.) Kuntze	Amaranthaceae	*Ageratum conyzoides* L.	Asteraceae
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae
Aristida setacea Retz	Poaceae	*Ammi majus* L.	Apiaceae
Bidens pilosa L.	Asteraceae	*Aristida hystrix* L.f.	Poaceae
Blepharis maderaspatensis (L.) B. Heyne ex Roth	Acanthaceae	*Bidens pilosa* L.	Asteraceae
Calyptocarpus vialis Less.	Asteraceae	*Blepharis maderaspatensis* (L.) B. Heyne ex Roth	Acanthaceae
Cardiospermum halicacabum L.	Sapindaceae	*Calyptocarpus vialis* Less.	Asteraceae
Cassia hirsuta L.	Fabaceae	*Cassia tora* L.	Fabaceae
Cassia tora (L.) Roxb.	Fabaceae	*Celastrus paniculatus* Willd.	Celastraceae
Celastrus paniculatus Willd.	Celastraceae	*elosia argentea* L.	Amaranthaceae
Centotheca lappacea (L.) Desv.	Poaceae	*Chloris barbata* Sw.	Poaceae
Centrosema pubescens Benth.	Fabaceae	*Chloris barbata* Sw.	Poaceae
Chenopodium vulvaria L.	Amaranthaceae	*Cocculus hirsutus* (L.) W. Theob.	Menispermaceae
Chloris barbata Sw.	Poaceae	*Crassocephalum crepidioides* (Benth.) S. Moore	Asteraceae
Chromolaena odorata (L.) R.M. King & H. Rob.	Asteraceae	*Crotalaria juncea* L.	Fabaceae
Commelina benghalensis L.	Commelinaceae	*Cynodon dactylon* (L.) Pers.	Poaceae
Crassocephalum crepidioides (Benth.) S. Moore	Asteraceae	*Cynoglossum furcatum* Wall.	Boraginaceae
Crotalaria juncea L.	Fabaceae	*Cyperus rotundus* L.	Cyperaceae
Curcuma longa L.	Zingiberaceae	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae
Cynodon dactylon (L.) Pers.	Poaceae	*Desmodium paniculatum* (L.) DC.	Fabaceae
Cyperus rotundus L.	Cyperaceae	*Digitaria ciliaris* (Retz.) Koeler	Poaceae
Dactylis glomerata L.	Poaceae	*Euphorbia heterophylla* L.	Euphorbiaceae
Desmodium paniculatum (L.) DC.	Fabaceae	*Galinsoga parviflora* Cav.	Asteraceae
Digitaria ciliaris (Retz.) Koeler	Poaceae	*Ichnocarpus frutescens* (L.) W.T. Aiton	Apocynaceae
Hygrophila erecta (Burm.f.) Hochr.	Acanthaceae	*Ipomoea obscura* (L.) Ker Gawl.	Convolvulaceae
Eragrostis sp. L.	Poaceae	*Melinis repens* (Willd.) Zizka	Poaceae
Erigeron bonariensis L.	Asteraceae	*Mimosa pudica* L.	Fabaceae
Euphorbia heterophylla L.	Euphorbiaceae	*Panicum maximum* Jacq.	Poaceae
Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	Poaceae	*Panicum virgatum* Roxb. ex Steud.	Poaceae
Ichnocarpus frutescens (L.) W.T. Aiton	Apocynaceae	*Parthenium hysterophorus* L.	Asteraceae
Indigofera hirsuta L.	Fabaceae	*Paspalum dilatatum* Poir.	Poaceae
Ipomoea staphylina Roem. & Schult.	Convolvulaceae	*Pennisetum polystachion* (L.) Schult.	Poaceae
Malvastrum coromandelianum (L.) Garcke	Malvaceae	*Richardia scabra* L.	Rubiaceae
Mimosa pudica L.	Fabaceae	*Stylosanthes fruticosa* (Retz.) Alston	Fabaceae
Panicum maximum Jacq.	Poaceae	*Themeda triandra* Forssk.	Poaceae
Panicum virgatum Roxb. ex Steud.	Poaceae	*Tridax procumbens* L.	Asteraceae

Cont...

difference between herbaceous species diversity of different land use systems (Table 4, Fig. 3).

Population structure: In summer season *Cynodon dactylon, Alternanthera sessilis, Panicum maximum, Chromolaena odorata, Mimosa pudica* and *Parthenium hysterophorus* were the most frequently occurring species which occurred in 13.79, 9.72, 9.09, 7.52, 7.52 and 5.96% of the quadrats respectively. Similarly, in winter season *Panicum maximum, Chromolaena odorata, Mimosa pudica, Panicum virgatum, Alternanthera sessilis and Parthenium hysterophorus* occurred most frequently which occurred in 13.08, 9.13, 8.0, 7.71, 5.08 and 4.52 of the quadrats respectively. In the present study *Parthenium hysterophorus* occurred in both the season in higher frequency. This may be due to the vigorous growth and seed dispersal trait of the species. Most of the most frequently occurring species in the

Table 1. Herbaceous species composition in the study site

Winter season		Summer season	
Name of the species	Family	Name of the species	Family
Parthenium hysterophorus L.	Asteraceae		
Paspalum dilatatum Poir.	Poaceae		
Passiflora foetida L.	Passifloraceae		
Pennisetum polystachion (L.) Schult.	Poaceae		
Pennisetum setaceum (Forssk.) Chiov.	Poaceae		
Cenchrus stramineus (Peter) Morrone	Poaceae		
Peperomia magnoliifolia (Jacq.) A. Dietr.	Piperaceae		
Plumbago zeylanica L.	Plumbaginaceae		
Portulaca oleracea L.	Portulacaceae		
Richardia scabra L.	Rubiaceae		
Sida cordata (Burm.f.) Borss.Waalk.	Malvaceae		
Sida cordifolia L.	Malvaceae		
Solanum nigrum L.	Solanaceae		
Sorghum halepense (L.) Pers.	Poaceae		
Sphagneticola trilobata (L.) Pruski	Asteraceae		
Stylosanthes fruticosa (Retz.) Alston	Fabaceae		
Synedrella nodiflora (L.) Gaertn.	Asteraceae		
Urena lobata L.	Malvaceae		
Urochloa lachnantha (Hochst.) A.M. Torres & C.M. Morton	Poaceae		
Vernonia cinerea (L.) Less.	Asteraceae		

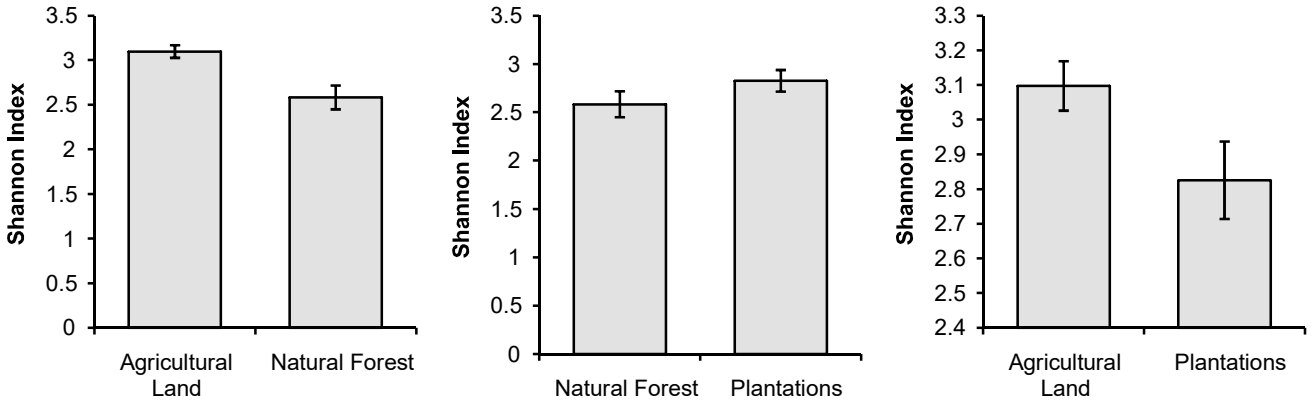

Fig. 3. Comparison of the Shannon diversities in different land use system

study site were observed to be the invading species. This is may be due to the intensive agricultural practices followed in the campus. Seasonal herb species were observed to be more frequent than that of perennials in the present investigation. The prevalence of seasonal herbaceous species as observed in this study could be largely due to seasonal variations in temperature and rainfall.

Cynodon dactylon (20.96), *Panicum maximum* (16.67) and *Parthenium hysterophorus* (16.03) had the highest IVI values (Table 4), respectively and ten dominant herbaceous speciescontributed 58% to the total IVI, in summer season. Similarly, in winter season *Panicum maximum* (26.25) *Chromolaena odorata* (18.28) and *Mimosa pudica* (15.94) showed the highest IVI (Table 4) and ten dominant herbaceous species contributed 61.86 % to the total IVI. Dominance of these species may be due to the environmental suitability and availability of optimum conditions for their growth and regeneration. Moreover, high IVI value by any individual species shows that most of the available resource are being utilized by that species and left over are being trapped by other species as the competitors and the associates (Shameem et al 2010). High importance value of a species indicates its dominance and ecological success, its good power of regeneration and greater ecological amplitude.

This study hints at the influence of changes in land use

Table 2. Species diversity indices of the study area for summer and winter season

Season/ Indices	Summer	Winter
Number of species	39	59
Shannon index	3.12	3.30
Simpson index	0.94	0.95
Evenness index	0.85	0.81

Table 3. Species diversity indices of the study area for different land use systems

Season	Summer			Winter		
Indices	Agricultural land	Forest	Planted forest	Agricultural land	Forest	Planted forest
Shannon	2.68	1.65	2.27	2.76	1.87	2.62
Simpson	0.90	0.79	0.87	0.90	0.73	0.90

Table 4. Comparison of the Shannon diversities of different land use systems using Hutcheson t-test

Land use system	Species richness	*H'*	Confidence interval	t-value	Degrees of freedom (df)	Critical value	p-value
Agricultural Land	46	3.10	0.07	6.78	430	1.97	<0.0001
Natural Forest	28	2.58	0.13				
Natural Forest	28	2.58	0.13	2.78	596.61	1.96	0.006
Plantations	39	2.83	0.11				
Agricultural Land	46	3.10	0.07	4.11	782.67	1.96	<0.0001
Plantations	39	2.83	0.11				

*Level of significance is 0.05

Table 5. Relative density, relative frequency, and IVI of the dominant herbaceous species in the study area

Species name	RD	RF	IVI	Species name	RD	RF	IVI
Summer				Winter			
Cynodon dactylon	17.13	3.82	20.96	*Panicum maximum*	13.18	13.08	26.25
Panicum maximum	12.45	4.22	16.67	*Chromolaena odorata*	9.16	9.13	18.28
Parthenium hysterophorus	10.60	5.43	16.03	*Mimosa pudica*	7.94	8.00	15.94
Alternanthera sessilis	9.23	2.93	12.16	*Panicum virgatum*	7.94	7.71	15.66
Chromolaena odorata	7.22	2.86	10.08	*Alternanthera sessilis*	5.05	5.08	10.13
Calyptocarpus vialis	4.10	4.55	8.65	*Parthenium hysterophorus*	4.49	4.52	9.00
Cyperus rotundus	2.73	5.37	8.10	*Cynodon dactylon*	4.11	4.14	8.25
Chloris barbata	0.73	7.16	7.89	*Cyperus rotundus*	3.93	3.95	7.88
Mimosa pudica	3.89	3.68	7.57	*Pennisetum polystachion*	3.08	3.10	6.19
Blepharis maderaspatensis	2.55	5.01	7.56	*Richardia scabra*	3.13	3.01	6.14

pattern around a semi-natural ecosystem. The results of the present study revealed high diversity of herbaceous in the biodiversity heritage site of GKVK campus. Herbaceous species diversity was highest in agricultural land use system compared to plantations and natural forests. Poaceae was represented by the highest number of species. The study site is dominated by the individuals of *Cynodon dactylon* in summer season and *Panicum maximum* in winter season. This study will provide baseline data for future conservation and management practices in the GKVK campus.

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Impact of Pre-sowing Seed Treatments on Germination, Growth and Biomass Characteristics of *Embelia tsjeriam-Cottam*

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***Abstract*:** *Embelia tsjeriam-cottam* Burm f. is an important medicinal plant and threatened species in the Western Ghats. Due to small embryo and its abortive nature, natural regeneration through seeds is particularly challenging. Therefore, the experiment was conducted to assess the impact of different pre-sowing treatments on germination, growth and biomass characteristics. The experiment was performed in pro-trays arranged in a randomised block design replicated thrice. Among various treatments, the scarified seeds soaked in GA_3 at 750 ppm was found best treatment and improved all parameters. Parameters of germination were found to be significant however growth and biomass parameters were found to be non-significant.

Keywords: Scarification, Germination, Pro-trays, *Embelia tsjeriam-cottam*, Seed soaking

Embelia tsjeriam-cottam, also called as Malabar Emelia, is a significant, red-listed medicinal plant of India with moderate demand in the domestic and international markets according to IUCN, (Sudhakar Raja et al 2005). It is a member of the Myrsinaceae family. *E. tsjeram-cottam* is a diverse plant that can be a little shrub that grows 1 to 2 metres tall to a small tree or even a twining climbing plant in hilly regions of India. It is also found in the Himalayas, between Kashmir and Sikkim, at elevations of 400 to 1600 metres in deciduous to semi-evergreen forests. It is valued for its digestive, thermogenic, carminative, depurative, anthelmintic, and laxative properties since immemorial time and frequently (Bhattacharjee 2000). It is also used to treat malignant tumours, asthma, bronchitis, diabetes, heart-related issues, nervous system illnesses, and liver issues. A polyphenol called gallic acid and a benzoquinone called Embelin are main active ingredient of the plant which have antioxidant and anticancer effects. The National Medicinal Plants Board has prioritized 32 medicinal plants for extensive cultivation to bring about a medicinal plant revolution in our nation that will benefit people's health and prosperity; *E. tsjeram-cottam* is one of these plants due to its commercial worth. This plant is reportedly threatened in Kerala, Tamil Nadu, Karnataka, and the Western Ghats. This plant's greatest concern is its indiscriminate and unsustainable harvesting for commercial interests. Its population is declining due to several circumstances, including habitat degradation, Jhum cultivation, forest fires, and increased agricultural production. This plant has very poor regeneration. At present, *E. tsjeram-cottam* embryos are relatively tiny, and most of the seeds are sterile. Specific habitat requirements are necessary for its survival and growth. *E. tsjeram- cottam's regeneration* is sluggish and extremely poor. Due to its similar properties to those of *E. ribes,* it has grown in trade value and demand in the local market. The demand for *E. ribes* expanded significantly between 1990 and 2000, and the export volume increased to 250 t/year (Mhaskar et al 2011). Due to excessive demand, this species was also heavily wild-harvested in protected and conserved regions. Therefore, care must be taken to ensure the survival of this significant medicinal plant. The ideal optional plant for *E. Ribes* is *Embelia team-Cottam* because it shares the same qualities (Devaiah et al 2008). Due to overharvesting, overexploitation, dispersed populations result in inbreeding, the formation of abortive embryos and the sluggish germination of small, less viable seeds, its natural regeneration is limited. Due to poor seed viability and low germination rates, artificial regeneration of both species is challenging (Annapurna et al 2013). Therefore, the investigation was carried to determine the effects of different seed treatments to develop best pre sowing seed treatment.

MATERIAL AND METHODS

Experimental site and detail: The investigation was carried out at the College of Forestry Dapoli, Ratnagiri, Maharashtra

during 2017-18. The experimental site is situated at an altitude of 252 metres above mean sea level and 17°76'77" North latitude and 73°19'10" East longitude.

The required seed material was collected from the village Tulshi, Tahasil Khed, Dist. Ratnagiri. The outer mucilaginous covering present in the seeds was removed. The seeds were treated with mercuric chloride 0.1% for 10 min, washed with tap water and shade dried for 24 hours. The scarified seeds were subjected to pre-seed treatments viz., GA_3 750 ppm, Ethylene 50 ppm, KNO_3 1.0 %, H_2SO_4 2.0 %, HCL 2.0 %, H_2SO_4 2.0% + GA_3 750 ppm and HCL 2.0% + GA_3 750 ppm for 24 hours and compared with control i.e., no treatment (only scarification).

The treated seeds were sown in portrays containing coco peat media which was kept in the greenhouse under 50% shade and watering was done regularly. Observations recorded were days to first germination, germination per cent, germination rate index, mean daily germination, peak value germination, germination value, shoot height, root length, the number of leaves, diameter, shoot fresh weight, shoot dry weight, root fresh weight and root dry weight.

RESULTS AND DISCUSSION

The minimum days required for first germination (1.45 days) were recorded against seed treated with scarification + soaking seeds in HCL 2.0% + GA_3 750 ppm for 24 hours (Table 1) while, maximum % germination (10.63), germination rate index (0.29), mean daily germination (0.13), peak value germination (0.15) and germination value (8.75) were recorded in response to scarification + soaking seeds in GA_3 750 ppm for 24 hours.

Among the different germination-inducing treatments, the seeds treated with gibberellins responded well with a high rate of germination and vigorous seedling growth. Early germination was seen in seeds treated with GA_3. This may be due to the instigative action of GA_3 for the germination of seeds. GA_3 induces the *de-novo* synthesis of proteolytic enzymes like amylase and ribonuclease. Amylases in turn hydrolyse starch in the endosperm, providing the essential sugars for the initiation of the growth processes of an embryo (Weiss and Ori 2007). GA_3 treatment is also known to overrule photo dormancy, thermo-dormancy, dormancy imposed by the rudimentary embryos, mechanical barriers, and the presence of germination inhibitors (Kitchen and Meyer 1991).

Similar results of increased germination attributes such as % germination, germination rate index, mean daily germination, peak value germination and germination value were observed in *E. ribes* (Shruthi et al 2016). The rate of germination, mean daily germination, germination value and vigour were also higher due to GA_3 treatment (Masoodi et al 2000). (Gowda et al 2003) reported that GA_3 at 400 ppm considerably improved germination (48%) than the control (12%) in *Embelia tsjeram-cottam.* The findings are also supported by (Mawalagedera et al 2014) in *Phyllanthus Emblica* in which seeds were scarified and treated with 1.00% gibberellins and Pipinis et al (2012) who revealed that 30, 60 and 90 min scarified seeds of *Paliurus spina-christi* Mill. after GA_3 application (500, 1000 and 2000 ppm), resulting in higher germination per cent compared to non-

Table 1. Impact of pre-sowing seed treatments on seed germination parameters of *E. tsjeram-cottam*

Treatments	Days to first germination	(%) germination	Germination rate index	Mean daily germination	Peak value germination	Germination value
Scarification control (T1)	9.45	2.06	0.05	0.02	0.03	1.45
Scarification +soaking seeds in GA_3 750 ppm for 24 hours (T2)	3.06	10.63	0.29	0.13	0.15	8.75
Scarification +soaking seeds in Ethylene50 ppm for 24 hours (T3)	4.89	9.36	0.24	0.11	0.12	8.56
Scarification +soaking seeds in KNO_3 1.0% for 24 hours (T4)	7.06	7.94	0.22	0.09	0.11	7.13
Scarification +soaking seeds in H_2SO_4 2.0% for 24 hours (T5)	9.31	9.36	0.23	0.11	0.14	7.57
Scarification +soaking seeds in HCL 2.0% for 24 hours (T6)	1.70	4.76	0.12	0.06	0.06	4.21
Scarification + soaking seeds in H_2SO_4 2.0%+GA_3 750 ppm for 24hours (T7)	7.22	5.88	0.14	0.07	0.11	5.25
Scarification +soaking seeds in HCL 2.0% + GA_3 750 ppm for 24hours (T8)	1.45	5.40	0.16	0.06	0.08	4.53
Mean	5.52	6.92	0.32	0.15	0.10	5.93
$SE_{m(\pm)}$	0.05	1.17	0.04	0.01	0.01	1.18
CD (p=0.05)	0.14	3.55	0.13	0.04	0.04	3.58

Table 2. Impact of pre-sowing seed treatments on growth parameters of *E. tsjeriam-cottam*

Treatments	Growth parameters			
	Shoot height (cm)	Root length (cm)	Number of leaves	Diameter (mm)
Scarification (control)	3.11	3.15	1.75	1.12
Scarification + soaking seeds in GA_3 750 ppm for 24hours (T2)	4.54	5.10	2.49	1.53
Scarification + soaking seeds in Ethylene 50 ppm for 24 hours (T3)	3.72	3.51	2.27	1.39
Scarification + soaking seeds in KNO_3 1.0% for 24 hours (T4)	4.24	4.81	2.29	1.48
Scarification + soaking seeds in H_2SO_4 2.0% for 24 hours (T5)	3.28	3.51	2.16	1.37
Scarification + soaking seeds in HCL 2.0% for 24 hours (T6)	3.81	4.00	2.10	1.45
Scarification + soaking seeds in H_2SO_4 2.0% + GA_3 750 ppm for 24 hours(T7)	3.81	3.91	2.17	1.47
Scarification + soaking seeds in HCL 2.0% + GA_3 750 ppm for 24 hours (T8)	3.53	4.03	2.27	1.41
Mean	3.71	4.36	2.19	1.40
SE_m (±)	0.54	0.65	0.19	0.08
CD (p=0.05)	NS	NS	NS	NS

Table 3. Impact of pre-sowing seed treatments on biomass parameters of *E. tsjeriam-cottam*

Treatments	Biomass parameters			
	Shoot fresh Wt. (gm)	Root fresh Wt. (gm)	Shoot dry Wt. (gm)	Root dry Wt. (gm)
Scarification (control) (T1)	3.11	3.51	2.16	1.37
Scarification + soaking seeds in GA_3 750 ppm for 24hours (T2)	4.54	5.10	2.49	1.53
Scarification + soaking seeds in Ethylene 50 ppm for 24 hours (T3)	3.72	3.51	2.27	1.39
Scarification + soaking seeds in KNO_3 1.0% for 24hours (T4)	4.24	4.81	2.29	1.48
Scarification + soaking seeds in H_2SO_4 2.0% for 24 hours (T5)	3.28	3.15	1.75	1.12
Scarification + soaking seeds in HCL 2.0% for 24 hours (T6)	3.81	4.00	2.10	1.45
Scarification + soaking seeds in H_2SO_4 2.0%+GA_3 750 ppm for 24 hours (T7)	3.81	3.91	2.17	1.47
Scarification + soaking seeds in HCL 2.0% + GA_3 750 ppm for 24 hours (T8)	3.53	4.03	2.27	1.41
Mean	3.71	4.36	2.19	1.40
SE_m(±)	0.54	0.65	0.19	0.08
CD (p=0.05)	NS	NS	NS	NS

Fig. 1. Pro-trays under greenhouse

Fig. 2. Scarified seeds of *Embelia tsjeriam-cottam*

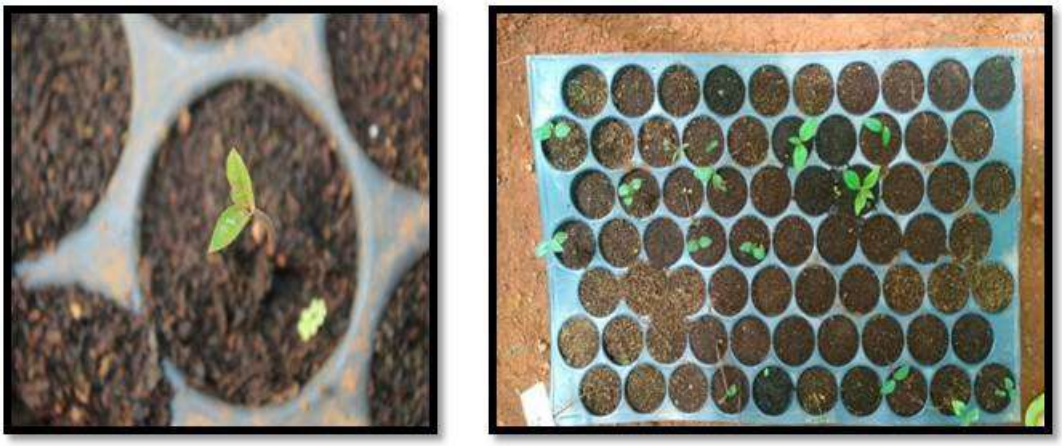

Fig. 3. Germination of *Embelia tsjeram-cottam* after 32 days

scarified seeds with GA_3. Similar results have been noticed by Maharana Rashmiprava et al (2018) in *Gmelina arborea.*

The data on the impact of scarification and seed-soaking treatments on growth parameters is presented in Table 2 and were found non-significant. The parameters related to growth such as shoot height, root length, number of leaves and diameter enhanced and recorded the highest values when scarified seeds were treated with GA_3 at 750 ppm for 24 hours (T2) and treatment T4 i.e., scarification +soaking seeds in KNO_3 1.0% for 24 hours (T4) was found to be the second better treatment. While, treatment T1 i.e., control i.e., only scarification recorded minimum values in all growth parameters.

The data recorded on the impact of scarification and seed soaking treatments on biomass parameters is found to be non-significant and given in Table 3. It has resulted that treatment T2 i.e., scarification + GA_3 at 750 ppm for 24 hours followed by treatment T4 i.e., scarification + soaking seeds in KNO_3 1.0% for 24hours increased all the parameters related to biomass such as shoot fresh weight, root fresh weight, shoot dry weight and root dry weight while, treatment T1 i.e., control (scarification) resulted in the least values.

CONCLUSION

From the investigations, it is concluded that scarified seeds of Malabar Embelia when pre-soaked with growth regulators, acids and their combinations recorded maximum values over control i.e., only scarification. All germination attributes except days to the first germination were higher when scarified seeds were treated with treatment T2 i.e., GA_3 750 ppm for 24 hours while the number of days to first germination were minimum with T8 i.e., scarification + soaking seeds in HCL 2.0 % + GA_3 750 ppm for 24 hours. Growth and biomass parameters were found to be non-significant but responded well with GA_3 and $KN0_3$.

AUTHORS CONTRIBUTION

A.D. Rane, S.S. Narkhede and V.K. Patil designed the study; Vaibhav R Jumale and Akshay Kailas Pingale collected data and developed draft of manuscript; Ankush Moran and Tapan Adhikari added additional data inputs and helped in laboratory; Pratik Santosh Kharat- Software.

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Preparation of *Aloe Vera* Powder by Different Drying Methods

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***Abstract*:** The present research was carried at PG Institute of Post Harvest Management in department of Medicinal Aromatic Plants, Spices and Forest Crops, Killa, Roha Maharashtra, India to find out suitable drying method and to standardize the *Aloe vera* powder preparation process. The physico-chemical properties of *A. vera* powder were evaluated to study storage stability. Packaging material and storage time significantly influenced all the parameters. Quality of powder showed good shelf life in convective tray drying method at 50ºC when packed in polyethylene bags. Storage for 90 days at room temperature did not affect the quality and was suitable for human consumption.

***Keywords*:** *Aloe vera,* Pulp, Powder, Drying methods, Storage

Aloe vera is a short-stemmed juicy plant with green pointed and fleshy leaves entrapping a clear viscous gel. It can achieve a stature of 60-100 cm with a spread up to 50-60 cm. It is native of Africa, the Arabian Peninsula, Madagascar and Indian Ocean Islands. *Aloe* species are also found in the Mediterranean region, Canary Islands, Mexico, India, and the Caraibes. The genus *Aloe* contains over 400 different species. However, *Aloe barbadensis* is considered the most biologically active species (Bozzi and Perrin 2007). In India, the major areas under *A. vera* cultivation are in Rajasthan, Andhra Pradesh and Gujarat (Jilariya et al 2017, Thakur et al 2018) and also found in the dry areas of states of Maharashtra and Tamil Nadu. Total production in India is estimated to be about 1,00,000 tonnes. Ayurvedic pharmacies are using only 1% of the total production from India (Anonymous 2006). The price of dried *A. vera* leaves in India ranges from Rs 600-1000 per kg depending upon the aloin content and colour of the dried *A. vera*.

Drying is one of the best methods for preserving the food materials. It increases the shelf life by decreasing the water activity in the product which inhibits the growth of microorganisms while decreasing spoilage reactions. Another important advantage of dried product is the reduction in the cost of packaging, storage and transportation due to their comparatively smaller volume and mass. The challenge of *A. vera* drying is to maximize the retention of nutrients while minimizing the moisture content of product to a level with restricted microbiological growth. A faster method of dehydration that yields a higher quality product is always required. It is generally known that freeze-drying produces highest quality dehydrated products, but this technique is very expensive and requires skilled operators. Hence, a method of convective drying could be a good solution. However, some problems like considerable shrinkage due to cell collapse following the loss of water, poor re-hydration characteristics of dried products and unfavourable changes in colour, texture, flavour and nutritive value may occur. This can be solved by controlled drying which helps in overall improvement in the quality of the final product (Ahmed and Singh 2013). Hence, the present study was undertaken to prepare *A. vera* powder by different drying methods to find out suitable powder drying methods and standardize the preparation process.

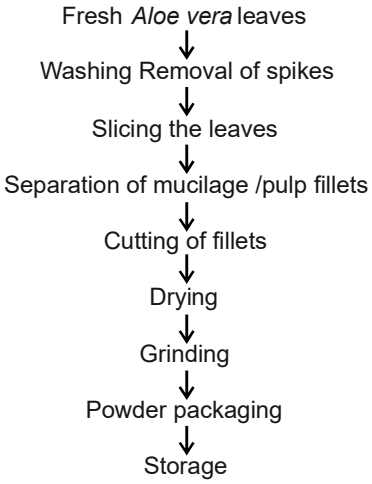
MATERIAL AND METHODS

The present study was conducted at the Department of Post Harvest Management of Medicinal, Aromatic, Plantation, Spices and Forest Crops, Post Graduate Institute of Post-Harvest Technology and Management, Killa - Roha, Dist. Raigad, Maharashtra India, north Kokan (18°42'5947" N, 73°17'9361" E) during 2020-2021. Data was collected on physical parameters of *A. vera* during drying such as initial moisture, final moisture, drying time and rate of drying. The data collected were statistically analysed by the standard procedure using Completely Randomized Design (CRD) with 4 main and 4 sub treatments having 5 replications. The observations on the changes in physical and chemical parameters of *A. vera* powder during drying and storage (at room temperature) were recorded at 0, 30, 60 and 90 days.

The leaves were cut in the early morning for experimentation to avoid moisture loss and spoilage. Each leaf was cut manually with a stainless-steel knife and pulled carefully from the mother plant to avoid breaking of rind. The leaves were transported from farm to the working place in a

covered polyethylene bag to avoid oxidation or contamination and were kept in upright position in order to drain out the 'aloin' (Yellow sap) present in it. After that leaves were washed under tap water to remove sticking materials and dirt. The spikes were removed before slicing the leaves. The thick dark green outer skin was peeled out manually from the thick gel fillet using a stainless-steel knife. The fillets were cut into 5 × 3 × 1 cm cuboids with the help of stainless-steel cutter and stored in an air tight container. The fresh cubes fillet was transferred into a tray for different drying methods *viz.*, sun, polytunnel, convective and microwave drying. *A. vera* pulp cubes/fillets placed for various dryer as per the treatment. Best treatment was selected on basis of statistical analysis for further study. From overall treatment and analysis, suitable drying method was standardized for preparation of *A. vera* powder. Temperature of convective dryer was kept 50º C and Microwave dryer was 60ºC. The sample was dried till constant weight was achieved. After complete drying, sample was ground and sieved to obtain the fine powder. Powder was packed in small polyethylene bag with the help of packaging machine. To find out suitable drying method and storage study, 60-80 g sample was filled in polyethylene bag. The storage was for 90 days and sample was analysed for different quality parameters at 30 days interval. The experiments were done with three replications. The preparation of *A. vera* powder is given in flow chart as under:

Process flowchart for preparation of *Aloe vera* powder



RESULTS AND DISCUSSION

Physical quality parameters of *Aloe vera* pulp: The results indicated that convection drying treatment recorded the highest initial moisture (98.70) per cent which was at par with treatment T3 and T2 (98.60 and 98.50 %) and T1 recorded the lowest initial moisture (98.2) per cent (Table 1). Muaz and Fatma (2012) also found 97 % moisture in the *A. vera* leaves.

The T4 recorded highest final moisture per cent (3.70) which was at par with treatment T3 whereas, T1 recorded significantly lowest final moisture per cent (2.10) which was followed by treatment T2. The present work agrees with Hendravati (2015). The final moisture per cent of *A. vera* pulp was 2.88, 4.04 and 4.89% at 140, 130 and 120º C temperature. Pattali and Yenge (2015) found 8.66 % final moisture in open yard sun drying, 8.61 % in hot air drying and 8.57 % in dehumidified air drying of *A. vera* leaves. Preetider and Amrit (2017) also found 3.59 % moisture in spray dried *A. vera* powder.

The T1 recorded significantly highest drying time (21.44 hr) which was followed by treatment T2 (Table 1). The T3 recorded the lowest drying time (14.44 hr) which was followed by treatment T4. Pattali and Yenge (2015) found that open yard sun drying, hot air drying and dehumidified air drying requires 21,16 and 11 hours, respectively for drying of *A. vera* pulp fillets.

The *A. vera* pulp in T3 recorded the significantly highest rate of drying (6.576) followed by treatment T4. Treatment T1 recorded the lowest rate of drying (4.48) which was at par with treatment T2. Sabat and Patel (2018) also observed that the drying rate increased with an increase in drying air temperature, resulting in a substantial decrease in the drying time. Pattali and Yenge (2015) found that drying process mainly consisted of three drying periods *i.e.* heating up, constant rate and falling rate period. In hot air drying at temperature of 50°C showed only the falling rate period which was due to moderate temperature of drying. The drying rate period decreased from 47.04 to 0.04 % at 50°C.

Physical quality parameters of the *Aloe vera* powder: The lightness of the colour in *A. vera* powder decreased significantly with increase in storage periods from 33.09 to 27.43 during 90 days storage (Table 2). Thus, it can be concluded that lightness of the colour in *A. vera* powder decreased with increase in storage period. The a* value increases with corresponding increase in storage period. The a* value of colour during storage of 0 to 90 days also increased significantly. Redness of the colour in *Aloe vera* powder increased with increase in storage period from 7.83 to 10.93 up to 90 days of storage. Interaction effect between storage period and different treatments was statistically non-significant. The b* value decreased with corresponding increase in storage period. The T3 recorded the highest mean b* value (38.43) for colour which was at par with T2. The b* value of colour during storage of 0 to 90 days also decreased significantly. Yellowness of the colour in *Aloe vera* powder decreased with increase in storage period from 39.98 to 32.48 up to 90 days storage. Interaction effect between storage period and different treatments was non-significant.

The decrease in the L* value and b* value while increase in a* value of dehumidified air-dried *Aloe vera* gel powder was recorded by Ramchandra and Srinivasa (2011).

The particle size during storage of 0 to 90 days slightly increased. Particle size in *Aloe vera* powder slightly increased with increase in storage period from 49.35 to 49.72 µ up to 90 days storage. Interaction effect between storage period and different treatments was non-significant. Gautam and Awasthi (2007) reported maximum water retention of the *Aloe vera* powder on 40 mesh size. Stoklosa and Lipasek (2012) observed the sticking and agglomeration resulting from exposure to relative humidity reduces flow ability and may be influenced by powder composition, particle size and shape.

Changes in the chemical quality parameters of the *Aloe vera* powder: The ash per cent during storage of 0 to 90 days also decreased significantly. Ash percent in *A. vera* powder decreased with increase in storage period from 15.70 to 15.49 per cent up to 90 days storage (Table 4). Similarly effect of drying method was non-significant and effect of storage period on ash also non-significant. Sabat and Patel (2018)y reported that temperature rise from 50 to 80ºC recorded 15.48 to 15.50 % ash, respectively. Gautam and Awasthi, (2007) found 14% ash content in the whole leaf tray

Table 1. Changes in the physical quality parameter of *Aloe vera* during drying

Treatments	Initial moisture %	Final moisture %	Drying time (Hour)	Rate of drying (% moisture/hour)
T1	98.20	2.10	21.44	4.48
T2	98.50	2.60	20.44	4.69
T3	98.60	3.10	14.44	6.58
T4	98.70	3.70	17.44	5.44
CD at 5 %	0.217	0.411	0.493	0.21

T1: Sun drying, T2: Polytunnel drying, T3: Microwave drying, T4: Convection drying

Table 2. Effect of different drying method and storage period on the L* colour value, a* colour value and the b* colour value of *Aloe vera* powder

Treatments (T)	L* Value					a* Value					b* Value				
	Storage (S) period (days)														
	0	30	60	90	Mean	0	30	60	90	Mean	0	30	60	90	Mean
T1	34.63	33.3	32.30	24.6	31.21	8.93	10.5	11.50	12.50	10.86	36.90	36.13	35.9	34.63	35.89
T2	28.23	27.17	26.4	25.57	26.84	7.40	9.90	10.90	12.25	10.11	41.83	39.33	37.67	34.73	38.39
T3	28.67	27.33	26.33	25.47	26.95	11.10	11.83	12.33	13.47	12.18	44.5	41.00	39.00	29.2	38.43
T4	40.83	41.53	40.23	34.10	39.18	3.87	4.70	5.07	5.5	4.78	36.7	35.00	34.00	31.33	32.48
Mean	33.09	32.33	31.32	27.43	31.04	7.83	9.23	9.95	10.93	9.48	39.98	37.87	36.64	32.48	32.48
	T		S		TxS	T		S		TxS	T		S		TxS
CD at 5%	2.56		2.56		NS	0.59		0.59		NS	1.82		1.82		NS

See Table 1 for details

Table 3. Effect of different drying methods and storage periods on the particle size, moisture and solubility of *A. vera* powder

Treatments (T)	Particle size (micron)					Moisture (%)					Solubility (min)				
	Storage (S) period (days)														
	0	30	60	90	Mean	0	30	60	90	Mean	0	30	60	90	Mean
T1	63.20	63.40	63.57	63.67	63.46	2.10	2.20	2.30	2.40	2.25	5.10	5.14	5.18	5.22	5.16
T2	53.10	53.30	53.40	53.50	53.33	2.60	2.70	2.80	2.90	2.75	5.10	5.14	5.18	5.22	5.16
T3	44.10	44.20	44.30	44.40	44.25	3.60	3.70	3.80	3.90	3.75	4.10	4.14	4.18	4.22	4.16
T4	37.00	37.10	37.20	37.30	37.15	3.70	3.80	3.90	4.00	3.85	3.10	3.14	3.18	3.22	3.16
Mean	49.35	49.50	49.62	49.72	49.55	3.00	3.10	3.20	3.30	3.15	4.35	4.39	4.43	4.47	4.41
	T		S		TxS	T		S		TxS	T		S		TxS
CD at 5%	11.07		11.07		NS	0.15		0.15		NS	0.06		0.06		NS

See Table 1 for details

Table 4. Changes in the Ash, fat and protein percentage of the *Aloe vera* powder during storage periods

Treatments (T)	Ash (%)					Fat (%)					Protein (%)				
	Storage (S) period (days)														
	0	30	60	90	Mean	0	30	60	90	Mean	0	30	60	90	Mean
T1	16.2	16.1	16.03	15.99	16.08	1.79	1.74	1.69	1.64	1.72	2.41	2.33	2.23	2.15	2.28
T2	17.2	17.1	17.03	16.99	17.08	1.81	1.78	1.75	1.73	1.77	3.3	3.27	3.23	3.19	3.25
T3	15.2	15.1	15.03	14.99	15.08	2.14	2.12	2.11	2.1	2.12	4.8	4.77	4.73	4.69	4.75
T4	14.2	14.1	14.03	13.99	14.08	2.2	2.18	2.14	2.11	2.16	4.83	4.8	4.77	4.72	4.78
Mean	15.7	15.6	15.53	15.49	15.58	1.98	1.96	1.92	1.9	1.94	3.83	3.79	3.74	3.69	3.76
	T		S		TxS	T		S		TxS	T		S		TxS
CD at 5%	NS		NS		NS	0.03		0.03		NS	0.12		0.12		NS

See Table 1 for details

Table 5. Changes in the fiber, pH and TSS of the *Aloe vera* powder during storage periods

Treatments (T)	Fibre (%)					pH					TSS				
	Storage (S) period (days)														
	0	30	60	90	Mean	0	30	60	90	Mean	0	30	60	90	Mean
T1	16.1	15.94	15.9	15.84	15.94	2.89	2.92	3.17	3.47	3.11	2.08	2.45	2.65	3.17	2.59
T2	16.39	16.33	16.23	16.1	16.27	3.92	3.94	4.13	4.47	4.12	3.03	3.48	3.86	4.03	3.6
T3	16.5	16.45	16.39	16.35	16.42	3.93	4.22	5.13	5.47	4.16	3.1	3.57	3.88	4.03	3.65
T4	16.62	16.57	16.51	16.47	16.54	3.7	4.16	4.64	4.73	4.31	4.03	4.35	4.65	4.95	4.5
Mean	16.4	16.32	16.26	16.19	16.29	3.61	3.74	4.04	4.3	3.92	3.06	3.46	3.76	4.05	3.58
	T		S		TxS	T		S		TxS	T		S		TxS
CD at 5%	0.12		0.12		NS	0.17		0.17		NS	0.08		0.08		NS

See Table 1 for details

dried *A. vera* powder sample at 50ºC. The fat, protein content and fiber percent of *Aloe vera* powder were decreased with corresponding increase in storage period from 0 to 90 days from 1.98 to 1.90, 3.83 to 3.69 and 16.40 to 16.19 per cent, respectively up to 90 days of storage. These results are supported by findings of fat, protein and fiber content per cent in *Aloe vera* powder by Sabat and Patel (2018). As acidity decreased pH of *Aloe vera* powder increased. The pH of *Aloe vera* powder was increased with corresponding increase in storage period 0 to 90 days from 3.61 to 4.30 (Table 5). The pH of *A. vera* powder at different drying methods was recorded by Sabat and Patel, (2018).

The TSS of *A. vera* powder increased significantly with corresponding increase in storage period of 0 to 90 days from 3.06 to 4.05 ºB. Interaction effect between storage period and different treatments was found to be statistically non-significant. TSS of spray dried powder of *Aloe vera* was 2.6 ºB recorded by Preetider and Amrit (2017). The moisture content during storage of 0 to 90 days was also increased significantly from 3.00 to 3.30 per cent. These results are in confirmative with moisture content of *A. vera* powder as recorded by Ramchandra and Srinivasa (2011). Preetider and Amrit (2017) was also reported 3.59 % moisture in spray dried *Aloe vera* powder while Hendravati (2015) noticed 2.88, 4.04, 4.89 and 4.89 % moisture in spray dried *Aloe vera* powder at temperature 140, 130, 120 and 110ºC, respectively. The solubility of *A. vera* powder slightly increased with corresponding increase in storage of 0 to 90 days from 4.35 to 4.47 min. Preetider and Amrit (2017) also reported solubility of *A. vera* powder was 100.54 sec. Gore and Devdas (2011) found solubility of spray dried *A. vera* powder 173 sec. Hendravati (2015) observed 2.26, 1.93, 2.94 and 2.94 min. solubility of spray dried *Aloe vera* powder at temperature 140, 130, 120 and 110 °C, respectively.

CONCLUSIONS

The quality *A. vera* powder with good shelf life was prepared by convective tray drying method at 50ºC and packed in polyethylene bags it is stored for 90 days at room temperature did not affect the quality and found suitable for human consumption.

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Environmental and Economic Role of *Tectona grandis*: A Case Study

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***Abstract*:** As a mitigation strategy to lower atmospheric carbon dioxide and boost farmers' net income, tree plantations are advocated as one of the biological tools to sequester carbon. Many tropical nations are implementing agroforestry-based carbon storage programmes; however, it is challenging to quantify the potential for carbon storage. The amount of carbon stored in the plantation, the potential to mitigate carbon from the atmosphere and the market value of 4 and 6-year-old *Tectona grandis* plantation in Chhattisgarh, India, was estimated. In the present study, the result indicated that the six-year-old plantation has the potential to produce 1650.90 ft^3 of the merchantable volume of timber with a market value of Rs. 20,63,621-1,15,57,929/- per hectare and the merchantable volume and market value produced in the plantation was 1097.87 ft^3 and Rs. 15,83,218-76,44,215/-. Similarly, the biomass and carbon stored in a six-year-old plantation was 309.00 t ha^{-1} and 127.36 t C ha^{-1} and in the four-year-old plantation it was 221.99 t ha^{-1} and 91.29 t C ha^{-1}. The CO_2 mitigation potential was 335.04 t $CO_2 ha^{-1}$ in a four-year-old plantation and 467.40 t $CO_2 ha^{-1}$ in a six-year-old plantation. The response in the India has been shown to be superior since teak is native to the forests of India and is produced on a modest to moderate scale. The results revealed that, with the increase in the age of teak plantations, there is an increase in carbon sequestration in plantations with a higher economic and ecological return.

Keywords: Teak, Economics, Carbon storage, CO_2 mitigation

Since the pre-industrial period, anthropogenic greenhouse gas emissions have risen significantly, mostly due to population expansion and industrialisation. Agroforestry is being investigated to mitigate increases in atmospheric carbon dioxide and projected climate change (Bhusara et al 2016). Many tropical nations are implementing forest carbon sequestration programmes; however, assessing carbon sequestration capacity is hindered by a lack of species-level data. Farmers may diversify their produce, decrease agricultural risk, contribute to food security, and earn much-needed revenue using these solutions. They also fulfil commercial timber needs while improving environmental values and services. Research on different tree species to evaluate their potential for carbon sequestration could help prioritise the best land use practices to ensure sustainability and benefit sharing among countries. The Kyoto Protocol recognises forests as one of the important carbon sinks. Research suggests that trees and other forest components sequester carbon within their bole, bark, branches, foliage, and roots for decades (Thakur et al 2011, Nizami 2012, Adnan and Nizmai 2014). The ability of various tree species to store carbon is mainly governed by the rotation of tree types and the age of plantations. With the additional benefit of being utilised mostly indoors, long-rotation species like teak (*T. grandis*) have a longer carbon locking time than short-rotation species (Sreejesh et al 2013). Teakwood trade has grown dramatically during the past few years. As long as its legal and sustainable farming has been established, teak is still highly valued and in great demand worldwide. Due to the growing volume of teakwood commerce, a systematic strategy to supply chain monitoring is required. As a result, starting on January 1, 2022, the Harmonized System nomenclature 2022 (HS 2022) Edition is bieng used to track the global trade in teakwood. The consistent classification of commodities traded worldwide are done using HS 2022. Togo's smallholder farmers cultivate teak on their properties to enhance household income. Food security is crucial since agricultural land and workers are in short supply. Despite this, farmers are eager to grow teak since the 15-year rotations offer the greatest yields for subsistence farmers (Kenny 2007). For similar reasons, smallholder farmers in southern Benin cultivate teak on short rotation to produce poles 5 to 15 cm long (Aoudji et al 2011). Farmers in Nigeria, under national afforestation initiatives and advancing national environmental goals, teak lengthens the time spent in a fallow state, improves soil fertility, diversifies agricultural output, and raises household income (Osemeobo 1989). However, access to land, technical knowledge, market expertise, and high-quality germplasm are necessary for farmers for such systems to perform to their full potential (Zanin 2005).

India's economic growth and rapid urbanisation are transforming the country's lifestyles and spending habits. The historic allure of wood and wood products in the nation is growing. An estimated 438.14 million m^3 of wood (including bamboo) is produced annually in India. India produces the most fuelwood (304 million m^3) (FAO 2021). *Tectona grandis* L.f., a large deciduous tree with a height of up to 40 m, is a member of the Lamiaceae family. Due to its stunning look and durable qualities, teak is one of the most expensive wood species. Despite being native to South and Southeast Asia, teak wood was imported into the agroforestry systems of several nations throughout tropical Asia, Africa, and Central and South America due to its tremendous economic potential (Nidavani and Mahalakshmi 2014, Udayana et al 2020). Farmers and foresters have recognised teak as a plant they like to domesticate (Thakur et al 2016, Kumar et al 2017, Pachas et al 2019). In India, the production of teak as a forestry business was a turning point in the development of forestry from a mainly extractive and regulating profession to one that involved resource creation. Teak was promoted with other main crops by the taungya systems in Myanmar (Blanford 1958), Java (Weersum 1982), and Africa (Oduol 1986). Since the introduction of clonal forestry, most teak plantations in tropical and subtropical nations have been grown from rooted cuttings and planting material obtained from tissue culture (Monteuuis and Maître 2007, Monteuuis and Goh 2017). Smallholder teak plantation refers to farmers with an average holding size of 0.5 to 1.0 ha and prefers agricultural systems incorporating teak trees, annual crops, and animals. Around 0.92 million acres of teak are grown by smallholders worldwide, with just 19% of the area being in Asia (Kollert and Cherubini 2012). In the 1960s, Indonesia developed the idea of contemporary smallholder agroforestry, primarily to produce teak wood. Later, it became a cutting-edge agroforestry model. Teak from small-scale plantations became a popular timber supply, producing more than large-scale plantations (Halladay and Gilmour 1995). Teak demand in and around the world exceeds the sustainable production from natural forests and plantations. The growing demand provides the opportunity for enterprising farmers. Teak is being farmed in smallholder agroforestry systems in several tropical nations. This research examines the role of teak systems in smallholder livelihoods and the C mitigation potential through block plantation.

MATERIAL AND METHODS

Study area: At a farmer's field in Bilaspur, Chhattisgarh, India, a 6 and 4-year-old clonal teak plantation were selected for the experiment. The site is located at 280 m above mean sea level, between 22°12' 05.21" N latitude and 82°05' 04.27" E longitude. The number of plants per hectare (2196) were higher in block plantations because they were planted in close spacing (2x2 m) to avoid deformation at early age.

Environment function: Allometric equations (Singh and Mishra 1979) linking tree circumference to biomass were utilised to assess tree biomass. Prior measurement of the carbon concentration (bole 43.50%, branch 45.67%, leaf 46.67%, and coarse root 35.73%) by Singh (2010) for the tropical dry deciduous forest of Chhattisgarh was utilised to estimate carbon stock. The carbon storage for vegetative components was determined by multiplying the dry weight of the components by their mean carbon content.

Economic function: By adhering to the prescribed protocols, field observations on significant growth factors, such as diameter at breast height (DBH) and individual trees height was recorded as per standard procedures. Tree stem volume was estimated using equation (FSI 1996): VUB (m^3) = -0.0645+ 0.2322D^2H, Where VUB is volume under bark, D is DBH over bark, and H is tree height. The average stem volume per tree was multiplied by the number of plants per hectare to determine the volume of stems per hectare in m^3/ha. In order to calculate the marketable value, it was converted to ft^3/ha. The market value of the standing crop was calculated using two market values (upper and lower limits) from the official website of India Mart.

RESULTS AND DISCUSSION

Economic function: The result showed that the average height of the four-year-old plantation was 3.04 m and that of six-year-old plantation was 4.11 m, and the merchantable height was 2.95 m and 3.36 m, respectively, for both plantations (Table 1). The diameter above the bark ranged between 32.30 and 56.00 cm at in four-year-old plantation and 40.90 and 60.90 cm of the six-year-old plantation. The

Table 1. Merchantable volume and market value of teak plantation

Plantation	Avg DBH (cm±SE)	Avg ht (m±SE)	Merchantable volume		Market value/ tree* (INR) (n=15)		Market value/ha* (10^6 INR)	
			m^3/ha±SE	ft^3/ha±SE	1450 ru/ft^3	7001 ru/ft^3	1450 ru/ft^3	7001 ru/ft^3
4-yr-old	45.01±1.65	2.95±0.07	30.92±2.14	1091.87±75.57	720.96	3480.97	1.58	7.64
6-yr-old	52.00±1.40	3.36±0.07	46.75±2.55	1650.90±90.15	939.72	5263.17	2.06	11.56

Source of market price per cubic feet- India Mart

merchantable volume of the four-year-old plantation was 30.92±2.14 m^3, and 46.75±2.55 m^3 of the six-year-old plantation. It could provide an additional income of 720 to 3,480 rupees per plant and around 1.58 to 7.64 million rupees per hectare in a 4-year-old plantation and 939-5,263 rupees per plant and around 2.06 to 11.56 million rupees per hectare in the six-year-old plantation. If the farmer uses the systemic thinning process to encourage higher per-hectare volume growth and removes only 1312 to 1625 plants per hectare, the plantation will generate an additional intermediate income of Rs 9,44,640-56,55,000 from 4 years and Rs 12,31,968 - 85,52,375 through 6-year-old plantation. Also, the increased gap between the row and column will also increase the space for short-term crops.

According to reports (ISFR 2019), the demand for sawn wood is now rapidly rising, and outside of forests, trees contribute the most to the production of wood (84%). In Gunungkidul village of Java, smallholders use teak plantations as their living saving account and harvest them only in significant need of money (Roshetko et al 2013). Also, the farmers in Luang Prabang sell their trees for cash in an instant need to cover unforeseen needs and significant annual bills like tuition (Antilla 2016). According to Monteuuis and Goh (2015), clonal plants with 3x3 m spacing at 5 years had an average output of roughly 25 cum per hectare yearly. After 50% of the trees were cut down systematically, 48.8 cum per hectare per year was recorded (Monteuuis and Goh 2018). Also, Mevada et al (2022), Kumar et al (2016) and Thakur et al (2016) observed that comparing the single crop net realisation and benefit cost ratio from teak-based agri-silviculture was greater.

Environmental function: The results (Table 2) of biomass and carbon stored in different plantations and their potential to mitigate the CO_2 from the atmosphere indicate that the biomass stored in the four-year-old plantation was 309.00±26.86 t/ha, with carbon stock 127.36±11.15 t C/ha, and it had the potential to eradicate the 467.40±40.91 t CO_2 per hectare. The bole contributed 91.98 t/ha and 40.01 t C/ha to biomass and carbon storage; the branch contributed 86.96 t/ha and 39.72 t C/ha; the foliage contributed 10.61 t/ha and 4.95 t C/ha; and the root component contributed the most (119.45 t/ha and 42.68 t C/ha). Similarly, the biomass storage capacity of the six-year-old plantation was 434.67 t/ha, with 179.59 t C/ha of carbon stored in it and the ability to absorb 659.08 t CO2 per hectare.

Here also, root component contributed the most to biomass and carbon storage (164.24 t/ha and 58.68 t C/ha, respectively), followed by bole (126.41 t/ha and 54.99 t C/ha), branch (129.90 t/ha and 59.33 t C/ha), and minimum by foliage component (14.12 t/ha and 6.59 t C/ha, respectively). Estimation of biomass is crucial for understanding carbon stocks (Ketterings et al 2001). Tree absorb carbon dioxide during photosynthesis and is fixed in their body biomass, and as a tree's biomass expands, its diameter likewise rises, increasing the tree's capacity to sequester carbon dioxide from the atmosphere (Pandya et al 2013). High biomass and carbon sequestration are substantially associated with the basal area and tree size (Vilanova et al 2018). Many times, teak plantations are selected since it is a species with significant commercial value. Teak is more effective at storing more carbon in its tissue for longer periods and emitting less carbon dioxide into the environment (Sreejesh et al 2013).

Although the contribution of root components in biomass and carbon storage is highest, with an increase in age, the contribution of wood components (bole and branch) increases. The contribution of short-lived components (foliage) in biomass and carbon storage is minimum, and they play an active role in carbon sequestration and the

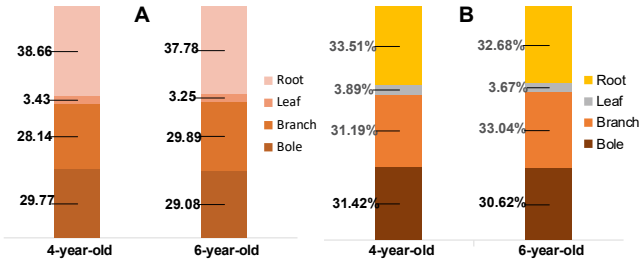

Fig. 1. Contribution of components a) stand biomass and b) stand carbon storage and CO^2 mitigation potential

Table 2. Biomass, carbon storage, and carbon mitigation potential of teak plantation

Plantation	Parameter	Bole	Branch	Leaf	Root	Total
4-year-old plantation	Biomass (t/ha±SE)	91.98±7.45	86.96±8.95	10.61±0.77	119.45±9.69	309.00±26.86
	Carbon storage (t C/ha±SE)	40.01±3.24	39.72±4.09	4.95±0.36	42.68±3.46	127.36±11.15
	CO_2 mitigation potential (t CO_2/ha±SE)	146.84±11.90	145.76±15.00	18.17±1.32	156.63±12.71	467.40±40.91
6-year-old plantation	Biomass (t/ha)	126.41±7.57	129.90±9.88	14.12±0.76	164.24±9.85	434.67±28.05
	Carbon storage (t C/ha)	54.99±3.29	59.33±4.51	6.59±0.35	58.68±3.52	179.59±11.67
	CO_2 mitigation potential (t CO_2/ha)	201.81±12.08	217.73±16.56	24.18±1.30	215.36±12.91	659.08±42.84

nutrient cycle (Singh and Singh 1991, Singh and Singh 1993). In the present study, the results favoured the results obtained by Singh and Singh (1991). The different studies conducted in the Chhattisgarh region supported the contribution of foliage in biomass and carbon storage (Singh 2010, Pawar 2014, Samal et al 2022, Thakrey et al 2022). Whereas the study by Shukla and Viswanath (2014) reported that the contribution of the bole component was highest.

CONCLUSION

The physical productivity and economic viability of an agroforestry system are significantly influenced by its woody components' temporal and spatial arrangements. The relative virtues of teak block plantings have been shown by data from this study's investigation of the economic and environmental benefits. Smallholder teak systems are a low-input alternative strategy for improving livelihoods. The techniques increase income and provide the option of redirecting family labour to non-farm pursuits. The system's fundamental element, the classic intercropping approach, enables the production of short-term and long-term profits. Smallholder teak systems have developed into a substantial source of raw materials for the furniture industry and have assisted in ecosystem restoration. In addition to the potential benefits and ongoing significance of smallholder teak systems, a teak block plantation may theoretically eliminate atmospheric CO_2 and store it in biomass that can be used to produce furniture and kept for a long time, which can assist in slowing down climate change.

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Performance and Comparative Advantage of Wood Products Trade from India

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***Abstract*:** The export of total wood products from India is 0.40% of total production, though India is importing 7107 thousand m^3 wood products. This indicates the huge demand of wood products in India. The export quantity and value of different wood products from India is less than the import which showed negative balance of trade for wood products. Therefore the present investigation was carried out with the objective to study the composition, percentage share of India in the world, growth, variability and comparative advantage of export and import of different wood products from India. Present investigation was based on secondary data collected from the official website of International Tropical Timber Organization for the period from 2001 to 2021. The quantity and value of export and import of total wood products raised during study period. Among the wood products exported from India, highest export quantity is in case of plywood and veneer while the percentage share of Industrial round wood and swan wood in total wood product export was less. The highest quantity and value of import from India was for industrial round where as it was less for plywood and veneer. The quantity of export and import of total wood products, plywood and veneer from India increased significantly where as the import of all the wood products. The export quantity of total wood product (47.72%) having higher variability than the import quantity of total wood products (32.81%). The higher variability in export and import quantity in veneer, plywood and swan wood. The values of revealed comparative advantage and revealed symmetric comparative advantage indicated that India had higher comparative advantage in export of veneer and plywood than the other wood products during the study period.

Keywords: Growth performance, Export, Comparative advantage, RCA

Wood is the important natural resource in the developing country like India. According to statistical database of International Tropical Timber Organization during the year 2001 the production of wood products in India was 55978.34 thousand m^3 which grew by 47% and reach up to 82480.03 thousand m^3 till 2021. Though various measures has been taken by the government to increase the forest cover in India, still India is deficit in wood production to cope up its increasing demand and meet its demand though importing the wood. Wood based industry is the fastest growing industry in India. The rapid growth in urbanization and increasing housing construction there is huge demand for wood and wood products. To meet these demand different wood products imported in India. The export of total wood products from India is 0.40% of total production, though India is importing 7107 thousand m^3 wood products. This indicates the huge demand of wood products in India. The export quantity and value of different wood products from India is less than the import which showed negative balance of trade for wood products. As wood based industry is one of the most important part of economy, the study on status and growth in trade of wood product over the period of time which may useful in taking future decisions in relation to production and trade of wood products. Therefore present investigation carried out to study composition of wood products export and import from India, variability in wood products export and import from India and comparative advantage of wood products export from India.

MATERIAL AND METHODS

The present investigation was carried by collecting the secondary data on quantity and value of export and import of different wood products from India from the statistical database given on the official website of International Tropical Timber Organization (ITTO) for the period from 2001 to 2021.The different wood products includes the industrial round wood, swan wood, veneer and plywood. Simple percentage was worked out to study the composition of wood products export and import from India.

Growth gate: To study the growth in quantity and value of export and import of wood products Compound Annual Growth Rate (CAGR) was estimated by fitting the exponential trend equation.

$$Y_t = ab^t$$

Where Yt is the dependent variable for which growth rate estimated (the quantity and value of export and import during

the year 't'), a is the intercept, b is the slope of exponential trend equation and t is the year or time period.

The above equation transformed in to log linear form as below

$$\text{Log } Y = \log a + t \log b$$

$$\text{Log } Y = A + Bt$$

Where A= log 'a' and B = log 'b'

The compound annual growth rate worked out as

$$CAGR = (\text{antilog } b - 1) \times 100$$

Variability: To determine the variability in quantity and value in export and import of wood products coefficient of variation was worked out.

$$CV = \frac{\sigma}{Y} \times 100$$

Where σ = Standard Deviation and Y = mean of quantity or value of export and import

Revealed comparative advantage (RCA): To measure comparative advantage in export of specific commodity Revealed Comparative advantage Index was estimated. This method was formulated by Balassa (1965) and it mathematical expression given as

$$RCA = (Xij/\sum Xik)/(Xwj/\sum Xwk)$$

Where,

Xij = Exports of country 'i' of commodity 'j'

Xik = Exports of country 'i' of all the commodities 'k'

Xwj = Exports of a world 'w' of commodity 'j', and

Xwk = Exports of a world 'w' of all the commodities'k'

Here 'i' refers to India, 'j' means the export quantity of particular wood product, 'w' means World and 'k' refers to total quantity of export of all the wood products. If the RCA index for a particular wood product estimated to greater than 1, indicated that the country has a revealed comparative advantage in the exports of that particular wood productand vice-versa. However RCA having the limitation of asymmetry, therefore to make RCA symmetric the another method was suggested by Dalum et al (1998) called as Revealed Symmetric Comparative Advantage (RSCA) was used. This index also adopted by Burange and Sheetal (2008), Shinoj and Mathur (2008) and Kerobim et al (2014) in their studies. Mathematically it is expressed as

$$RSCA = \{ (Xij/\sum Xik)/(Xwj/\sum Xwk) + 1 \}$$

The value of RSCA index range between +1 and -1. If the value of RSCA index is positive then it indicated that the country had comparative advantage in export of that specific commodity and vice-versa.

RESULTS AND DISCUSSION

Composition of wood products export and import: The quantity and value of wood product export from India raised during the study period (Table 1). During the year 2001 the quantity of export and value of total wood product was 49.28 thousand m^3 and 16848.47 thousand US$ which raised to 327.74 thousand m^3 and 133296.50 thousand US$ during the year 2021, respectively. The quantity and value of export of Industrial round wood and swan wood decreased whereas it was increased in case of veneer and plywood during the period 2001 to 2021. Among the wood products exported from India the highest export quantity and value was of plywood which was 75.58 and 43.56% during the year 2021, respectively followed by veneer wood. The percentage share of Industrial round wood and swan wood in total wood product export was found less as compared to the percentage share of veneer wood and plywood export.

The quantity and value of wood product import from India raised during the study period (Table 2). During the year 2001 the quantity of import and value of total wood product was 2868 thousand m^3 and 529121.3 thousand US$ which raised to 7210.57 thousand m^3 and 2115774 thousand US$ during the year 2011 and to 7107.25 thousand m^3 and 1822212 thousand US$ during the year 2021, respectively. Among all the wood products the highest quantity and value of import from India in industrial round wood which was 67.75 and 57.04% of total wood products import during the year 2021 whereas less quantity and was in case of plywood followed by veneer. The import of industrial round wood from India in terms of quantity increased from 2784.76 thousand m^3 during

Table 1. Composition of wood product export from India

(Quantity in 1000 m^3 and Value in 1000US$)

Wood product	2001		2011		2021	
	Quantity	Value	Quantity	Value	Quantity	Value
Ind. Round wood	5.41 (10.98)	1085.65 (6.44)	12.87 (9.40)	2538.37 (4.60)	7.22 (2.20)	33349.86 (25.02)
Swan wood	12.00 (24.35)	5876.58 (34.88)	61.99 (45.26)	15514.92 (28.11)	12.45 (3.80)	9828.17 (7.37)
Veneer	2.08 (4.22)	5191.02 (30.81)	12.92 (9.43)	18466.61 (33.45)	60.35 (18.41)	32058.25 (24.05)
Plywood	29.79 (60.45)	4695.22 (27.87)	49.18 (35.91)	18680.21 (33.84)	247.72 (75.58)	58060.22 (43.56)
Total wood products	49.28 (100)	16848.47 (100)	136.96 (100)	55200.11 (100)	327.74 (100)	133296.50 (100)

Source: Statistical database of The International Tropical Timber Organization
Figure in parenthesis indicate percentage to total wood product

year 2001 to 4815.24 thousand m^3 during the year 2021 but in terms of percentage of total wood products import declined from 97.10 to 67.75% during the year 2021. In terms of percentage of total wood products the quantity of swan wood import from India increased from 1.33% during the year 2001 to 23.22% during 2021.

World total export and import: The percentage share of India in world total wood products export increased over the period of time (Table 3). During the year 2001, India had 0.02% share in quantity of world total wood products export which increased up to 0.10 % during the year 2021. Among the wood products the quantity and value of veneer and plywood export from India recorded increasing share in world veneer and plywood export. The quantity of veneer and plywood export from India had 0.07% and 0.14% share in world veneer and plywood export during the year 2001 which raised to 0.87% and 0.81% during the year 2021. The share Industrial round wood and swan wood export from India in world total industrial round wood and swan wood export was very less and declined over the study period.

During 2001, the percentage share of quantity of total wood products from India in world wood product export was 1.12% which increased to 2.70% during 2011 and then declined to 2.11% during 2021 (Table 4). During the year 2001the percentage share of total wood products from India in world wood product export was 1.24% which increased to 3.11% during 2011 and then declined to 1.87% during 2021. The share of quantity and value of veneer import from India in world total veneer import found increased over the study period.

Growth and variability in export and import: The compound annual growth rate of export and import of different wood product from India during the period 2001-2021 is given in Table 5. The quantity and value of export and

Table 2. Composition of wood product import from India

(Quantity in 1000 m^3 and Value in 1000 US$)

Wood product	2001		2011		2021	
	Quantity	Value	Quantity	Value	Quantity	Value
Ind. Round wood	2784.76	509815.8 (96.35)	6341.35 (87.95)	1803056 (85.22)	4815.24 (67.75)	1039367 (57.04)
Swan wood	38.11 (1.33)	8541.14 (1.61)	591.81 (8.21)	159917.8 (7.56)	1650.35 (23.22)	387053.9 (21.24)
Veneer	2.88 (0.10)	2523.14 (0.48)	77.32 (1.07)	46066.58 (2.18)	452.46 (6.37)	294843.3 (16.18)
Plywood	42.25 (1.47)	8241.26 (1.56)	200.09 (2.77)	106733.7 (5.04)	189.2 (2.66)	100947.4 (5.54)
Total Wood Products	2868 (100)	529121.3 (100)	7210.57 (100)	2115774 (100)	7107.25 (100)	1822212 (100)

Source: Statistical database of The International Tropical Timber Organization
Figure in parenthesis indicate percentage to total wood product

Table 3. Percentage share of India in world total export of wood products

Wood product	2001		2011		2021	
	Quantity	Value	Quantity	Value	Quantity	Value
Ind. Round wood	0.00	0.01	0.01	0.02	0.00	0.20
Swan wood	0.01	0.03	0.05	0.05	0.01	0.02
Veneer	0.07	0.22	0.48	0.62	0.87	0.72
Plywood	0.14	0.07	0.19	0.13	0.81	0.31
Total wood products	0.02	0.01	0.05	0.02	0.10	0.01

Table 4. Percentage share of India in world total import of wood product

Wood product	2001		2011		2021	
	Quantity	Value	Quantity	Value	Quantity	Value
Ind. Round wood	2.37	5.53	5.24	9.89	3.31	5.56
Swan wood	0.03	0.04	0.50	0.47	1.08	0.70
Veneer	0.10	0.10	2.75	1.44	6.09	6.39
Plywood	0.20	0.11	0.80	0.83	0.61	0.53
Total wood products	1.12	1.24	2.70	3.11	2.11	1.87

Table 5. Growth rate of export and import of wood products from India

Wood product	Export		Import	
	Quantity	Value	Quantity	Value
Ind. Round wood	0.51	17.77***	2.64**	3.41**
Swan wood	1.01	5.14**	21.62***	23.77***
Veneer	5.10*	5.08***	30.86***	28.86***
Plywood	6.71***	8.58***	13.98***	15.68***
Total wood products	5.23***	8.85***	4.80***	6.67***

Note: *, ** and *** indicates significant at 10%, 5% and 1% level of probability

Table 6. Variability in export and import of wood products from India (%)

Wood product	Export		Import	
	Quantity	Value	Quantity	Value
Ind. Round wood	44.27	42.24	30.64	158.65
Swan wood	69.32	94.62	95.51	62.68
Veneer	85.16	109.14	106.56	37.19
Plywood	71.63	63.54	67.44	51.65
Total wood products	47.72	42.08	32.81	52.46

import of total wood products increased over the period of time increased significantly by 5.23 and 4.80% per annum whereas the value of export and import of total wood products increased by 8.85 and 6.67% per annum during the period from 2001 to 2021, respectively. The highest significant positive compound growth rate in quantity and value of export from India recorded in plywood export (6.71 and 8.58% per annum, respectively) which was followed by veneer export. This implied that the export quantity and value of plywood and veneer from India increased significantly during the study period. In case of industrial round wood and swan wood significant positive growth recorded in export only. The highest significant compound annual growth rate for import quantity was in Veneer (30.86%) followed by Swan wood (21.62%) and plywood (13.98%) whereas for import value it was highest for veneer (28.86%) followed by swan wood and plywood. This indicated that the import quantity and value of veneer, swan wood and plywood increased significantly in India. The growth in import quantity of industrial round wood, swan wood, veneer and plywood was higher than the growth rate of export quantity of these commodities implied that the import was higher than the export of these wood products in

Table 7. RCA and RSCA of wood product export from India

Year	Ind. Round wood		Swan wood		Veneer		Plywood	
	RCA	RSCA	RCA	RSCA	RCA	RSCA	RCA	RSCA
2001	0.24	-0.61	0.54	-0.30	3.77	0.58	7.41	0.76
2002	0.31	-0.53	0.38	-0.45	5.44	0.69	7.60	0.77
2003	0.49	-0.34	0.91	-0.05	8.36	0.79	3.29	0.53
2004	0.15	-0.74	0.52	-0.32	22.34	0.91	4.86	0.66
2005	0.23	-0.62	0.40	-0.43	25.55	0.92	4.71	0.65
2006	0.41	-0.42	0.40	-0.42	20.67	0.91	4.35	0.63
2007	0.13	-0.77	0.31	-0.52	15.92	0.88	6.34	0.73
2008	0.13	-0.77	0.74	-0.15	21.00	0.91	3.89	0.59
2009	0.15	-0.73	0.48	-0.35	20.67	0.91	5.21	0.68
2010	0.09	-0.83	0.54	-0.30	8.15	0.78	6.72	0.74
2011	0.21	-0.65	1.02	0.01	9.31	0.81	3.78	0.58
2012	0.19	-0.68	1.12	0.05	6.07	0.72	3.39	0.54
2013	0.10	-0.81	1.40	0.17	5.93	0.71	2.82	0.48
2014	0.16	-0.73	0.56	-0.28	3.53	0.56	7.26	0.76
2015	0.23	-0.63	0.55	-0.29	5.71	0.70	6.19	0.72
2016	0.32	-0.52	0.41	-0.42	5.06	0.67	6.65	0.74
2017	0.38	-0.45	0.58	-0.26	4.93	0.66	5.30	0.68
2018	0.13	-0.76	0.58	-0.27	10.15	0.82	5.86	0.71
2019	0.11	-0.80	0.68	-0.19	6.77	0.74	6.06	0.72
2020	0.11	-0.80	0.06	-0.88	17.30	0.89	7.71	0.77
2021	0.05	-0.90	0.08	-0.85	9.09	0.80	8.44	0.79

India. This may be due to higher domestic demand of these wood products in the country. Kant and Nautiyal (2022) reported that due to the growing middle-class population, increasing urbanization and rising disposable incomes boost the furniture industry to grow considerably which demand higher quantity of wood.

The export quantity of total wood product (47.72%) having higher variability than the import quantity of total wood products (32.81%) which indicated that there were variation in export quantity of total wood products from India over the study period. The highest variability in export quantity was in veneer (85.16%) followed by plywood and swan wood where as in case of import quantity the highest variability was for veneer (106.56%) followed by swan wood and plywood (63.54%) indicated that there was instability in export and import quantity of these wood products over the period of time in India. The higher variation in import quantity of veneer may be due to higher significant positive growth in import quantity of veneer in India. Among the wood products the highest variation for export value was in veneer (109.14%) where as the highest variation for import value found in case of industrial round wood (158.65%) during the study period (Table 6).

Revealed comparative advantage and revealed symmetric comparative advantage: In case of industrial round wood and swan wood the values of RCA were less than one and values of RSCA were negative implied that India had mostly comparative disadvantage in export of these wood products (Table 7). The RCA was greater than one and values of RSCA worked out to positive for export of veneer and plywood form India indicated that India had enjoyed higher comparative advantage in export of these commodities than the other wood products during the study period.

CONCLUSION

The quantity and value of export and import of total wood products raised during study period. Among the wood products exported from India the highest export quantity and value was in plywood and veneer while the percentage share of industrial round wood and swan wood in total wood product export was less. The highest quantity and value of import from India found for industrial round where as it was less for plywood and veneer. The share of quantity and value of veneer import by India in world total veneer import increased over the study period. The quantity of export and import of total wood products, plywood and veneer from India increased significantly where as the import of all the wood products was higher than the export during the study period. The export quantity of total wood product (47.72%) having higher variability than the import quantity of total wood products (32.81%). The higher variability in export and import quantity in veneer, plywood and swan wood. The values of RCA and RSCA indicated that India had higher comparative advantage in export of veneer and plywood than the other wood products during the study period.

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Community Structure of Lesser Known Tree Species, *Dalbergia lanceolaria* L. f., in Tropical Deciduous Forest

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Abstract**:** *Dalbergia lanceolaria* is an underutilised tree species having anti-inflammatory and anti-rheumatic properties being used in the ayurvedic system. The present study is framed to study the community structure of the species in the Northern western ghats region by laying out 20m x 20m plots in the identified patches of *D. lanceolaria* and regeneration pattern was studied by plotting 1m x 1m plots around the selected trees. *D. lanceolaria* occupied the upper storey of the deciduous forests, the close associates for the species were found to be *Tectona grandis*, *Terminalia tomentosa*, *Madhuca longifolia* and *Garuga pinnata* in the study area. Most of *D. lanceolaria*'s population was concentrated in the vicinity of streamlets or other water sources. The population showed a negatively skewed distribution of individuals, with maximum individuals in the 160-190 cm girth class while not even a single pole-stage individual was recorded. *D. lanceolaria* was observed regenerating by root suckers like other *Dalbergia* species. Its regeneration was observed to be more near the base and reduced later without any pattern. The study reveals threat to *D. lanceolaria* survivability in the future hence urgent attention should be paid towards the protection of natural regeneration and creating awareness among the local people.

Keywords**:** *Dalbergia lanceolaria*, Dang forest, Important value index, Natural regeneration, Stand structure

India harbours 11.4 per cent of plant diversity within its land mass 2.4 per cent of the world geographic area (Arisdason and Lakshminarasimhan 2020). Diversity of species is a sign of sustainability, especially tree diversity. Loss of tree diversity can ultimately lead to ecosystem collapse (Rivers et al 2022). Increased anthropogenic pressure on the natural forests as well as climate change drives many plant species into the threatened category (Primack 2006). In the last five decades, the world has faced an extreme rate of species extinction (loss of 137 species per day) which is 1000-10000 times the natural process of species extinction rate (Hilton-Taylor 2000, Moram et al 2011). A large number of tree species which were abundant or stable in the ecosystem once upon a time are declining now without any knowledge. *Dalbergia lanceolaria* L. f. could be one such lesser known species and population of this species is decreasing throughout the world (IUCN Red list 2022). It is a medium-sized lesser-known tree species belonged the Rosewood family, Fabaceae and the species is distributed in tropical deciduous forests of Bhutan, Nepal, Sri Lanka, Bangladesh, Myanmar, Thailand, Cambodia, Laos and Vietnam including different parts of India *viz.,* peninsular, eastern and some portions in the central India (Sam et al 2004, Dholariya et al 2019). In Sri Lanka, *D. lanceolaria* has entered into Red Data Book and is categorized as 'Vulnerable' (BGCI 2021). IUCN recently assessed its population status globally and categorised as least concerned (LC) (IUCN red list 2022). Even in Gujarat, this species is recognizing as one of the rare plants (Anonymous 2011). Documentation of population characters and community structure including auto-ecology play a vital role in categorizing the species into conservation concern, and also for its sustainable management in the wild (Hegde et al 2018). Therefore, the present study was undertaken to understand the composition, community structure, demography and natural regeneration of *D. lanceolaria* in one of the natural forest areas of South Gujarat.

MATERIAL AND METHODS

To study ecological attributes of *D. lanceolaria,* a reconnaissance survey was carried out in the natural forest of Unai forest range, Vyara division, South Gujarat in 2021. The study area spreads in northern most region of Western Ghats, India, near the Vansda National Park and Purna Wildlife Sanctuary (Anonymous 2020). The study area is recognized as forest type 3B/C1c of Slightly Moist Teak Forest (Champion and Seth 1968). The area is lateritic, deep black soil and alluvial soil along the Ambica river with gentle slope to moderate landmass, and receives 1344 mm average annual rainfall with temperature range of 6°C in January to 39°C in April (Pandya and Yadav 2014). In the present study, a focal population of *D. lanceolaria* distributed in the Unai

forest range was identified. A total of fifteen quadrates of 20 m x 20 m size were laid out randomly across the populations. Species composition, tree height, GBH (Girth at Breast Height @1.37 m) and crown diameter of all the trees having ≥ 30 cm girth within the quadrates were recorded. Checklist of species was prepared. For studying the regeneration pattern of *D. lanceolaria,* a single tree in each plot (*i.e.,* total 15 trees) was selected, 1 m x 1 m subplot around the selected trees at different distances *viz.,* 2, 4, 6, 8 and 10 m from tree base in all the four directions of the standing tree (North, South, East and West) was laid out (Gunaga et al 2012). Numbers of regenerating individuals and their growth parameters in each plot were recorded. Further, the regenerating individuals were classified into regeneration classes *viz.,* Class-I = seedling height < 40 cm, Class-II = seedling height 40-100 cm, Class-III = seedling height > 100 cm with girth < 10 cm, and Class-IV = height > 100 cm with girth 10- 30 cm (Behera et al 2014, Patwardhan et al 2017). Data recorded in the quadrates were used for assessing ecological parameters such as density, relative density, frequency, relative frequency, basal area, relative dominance and importance value index (IVI) as per standard formulae (Sharma 2017).

RESULTS AND DISCUSSION

Spread of *D. lanceolaria* in a population is showed clumped distribution and mostly they are thriving near the streamlets and other water bodies located in the deciduous forest. Considering species composition, total 102 individuals were recorded, composed of 20 species including *D. lanceolaria,* from 17 genera belonged to 13 families (Table 1). Fabaceae is the most prominent family represented by six different species. Moreover, other two species of *Dalbergia i.e., D. latifolia* and *D. paniculata* also co-existed in the studied plots. *Tectona grandis* and *Terminalia tomentosa* were represented in almost 80% of the studied plots, followed by *Garuga pinnata*. The upper strata is occupied by *T. grandis, T. tomentosa, Madhuca longifolia, Miliusa tomentosa* and *G. pinnata,* whereas in the middle strata, *Diospyrus melanoxylon, Butea monosperma, Wrightia tinctoria* were represented*;* however, *Carissa carandus* and Bamboo occupied the lower strata. Density of tree species ranged from 1.67 to 61.67 ha^{-1}, and the total tree density and basal area of the studied stands were 170 trees ha^{-1} and 27.69 m^2 ha^{-1}, respectively (Table 1). The highest density (61.67 ha^{-1}), frequency (100 %) and basal area (13.25 ha^{-1})

Table 1. Species composition and phyto-sociological attributes of *Dalbergia lanceolaria* populations in Vyara forest

Species	Family	*n*	Density (ha^{-1})	Frequency	Basal area (m^2/ha)	IVI
Dalbergia lanceolaria	Fabaceae	37	61.67	100.00	13.25	108.31
Associated species						
Adina cordifolia	Rubiaceae	2	3.33	13.33	0.42	6.71
Bahunia malbarica	Fabaceae	1	1.67	6.67	0.11	3.01
Butea monosperma	Fabaceae	5	8.33	20.00	0.60	11.91
Casearia spp.	Flacourtiaceae	2	3.33	6.67	0.19	4.25
Dalbergia latifolia	Fabaceae	6	10.00	20.00	0.95	14.14
Dalbergia paniculata	Fabaceae	1	1.67	6.67	0.25	3.51
Diospyrus melanoxylon	Ebenaceae	2	3.33	13.33	0.18	5.82
Garuga pinnata	Burseraceae	6	10.00	26.67	1.08	16.22
Gmelina arborea	Lamiaceae	1	1.67	6.67	0.09	2.92
Madhuca longifolia	Sapotaceae	6	10.00	26.67	1.81	18.88
Mangifera indica	Anacardiaceae	1	1.67	6.67	0.42	4.11
Miliusa tomentosa	Annonaceae	5	8.33	33.33	0.79	15.81
Ougeinia oojeinensis	Fabaceae	1	1.67	6.67	0.33	3.77
Schliechera oleosa	Sapindaceae	1	1.67	6.67	0.07	2.84
Spathodea roxburghii	Bignoniaceae	2	3.33	13.33	0.33	6.37
Tectona grandis	Lamiaceae	12	20.00	46.67	3.11	34.27
Terminalia bellirica	Combretaceae	2	3.33	6.67	2.36	12.08
Terminalia tomentosa	Combretaceae	8	13.33	40.00	1.28	22.15
Wrightia tinctoria	Apocynaceae	1	1.67	6.67	0.08	2.89
Total		102	170	413.33	27.69	

n=Number of individuals

was recorded for *D. lanceolaria* and appeared to be dominant in the studied population, since all those plots were laid out in the populations of *D. lanceolaria* by following selective sampling method. Among the associated species, maximum tree density was recorded in *Tectona grandis* (20.0 ha^{-1}), followed by *Terminalia tomentosa* (13.3 ha^{-1}) and least (1.6 ha^{-1}) in *Bauhinia malabarica*, *Dalbergia paniculata*, *Gmelina arborea*, *Mangifera indica*, *Ougeinia oojeinensis*, *Schleichera oleosa* and *Wrightia tinctoria*. Again, *Tectona grandis* (47 %) and *Terminalia tomentosa* (40 %) recorded the maximum frequency of occurrence followed by *Miliusa tomentosa* (33 %). The basal area of individual tree species varied from 0.07 to 13.25 m^2 ha^{-1}. *D. lanceolaria* recorded highest basal area of 13.25 m^2 ha^{-1}, followed by *Tectona grandis* and *Terminalia bellirica* and it was least in *Schleichera oleosa* (0.07 m^2 ha^{-1}). IVI, Importance Value Index varied from 2.84 (*Schliechera oleoasa*) to 108.31 (*D. lanceolaria*). Among the associates, *Tectona grandis* (34.27) exhibited highest IVI followed by *Terminalia tomentosa*, *Madhuca longifolia* and *Garuga pinnata*. In the present study, *D. lanceolaria* represents almost 35% of the population, followed by *Tectona grandis*, *Terminalia tomentosa*, *Madhuca longifolia* and *Garuga pinnata,* which shares 30%. However, remaining 35 % composition is from the rest of 15 species. The composition and growth of associated species in a stand are influenced by the combined effect of site factors *viz*. climatic, edaphic, topographic and biotic factors (Khanna 2009). A study carried out nearby Purna Wildlife sanctuary by Kumar et al (2018) also recorded that *Tectona grandis* and *Terminalia tomentosa* are the dominant species which represents IVI values of 44.53 and 43.83, respectively. Such pattern was also observed in Mahua populations of Gujarat (Hegde et al 2018). Furthermore, composition study carried out in the dry deciduous forest of Karnataka also recorded the *D. lanceolaria* with 45 associated species including *Terminalia paniculata*, *T. tomentosa*, *Tectona grandis* and *Dalbergia latifolia* (Prakasha et al 2008).

Girth class distribution of *D. lanceolaria* exhibits an unimodular, negatively skewed distribution (Fig. 1). The maximum proportion of individuals *i.e.,* 48.64 per cent was in 160-190 cm GBH class, followed by 21.62% in 130-160 cm class and 13.51% in 100-130 cm class. In both extreme girth classes (70-100 cm and 220-250 cm), the proportion of *D. lanceolaria* individuals was least with 2.70% representation. Surprisingly, there was no single individual observed within the 70 cm girth class. Lack of individuals in the lower girth classes poses a conservation risk for the species in the coming days. In undisturbed natural forests, good regenerating species usually exhibit inverted J shaped curve (Gonçalves et al 2017). The largest density of *D. lanceolaria* falls within 130-160 cm girth class may signifies quite even-aged stand in the forest. Absence of lower sized individuals of this species could be attributed by anthropogenic pressure like over-grazing of cattle in the stand, since leaf is palatable in nature (Dholariya et al 2019) and/or use of pole stage individuals for making of handles for agriculture tools by local people, that is why locally called as 'Dandoshi' means 'stick or pole' for this tree.

Natural regeneration pattern varies from species to species, place to place, and local habitat in accordance with availability of growing conditions like moisture, soil, *etc*. (Khanna 2009). Based on available regeneration data, more regeneration count (0.13 per m^2; 41.87 per 10 m radius) was represented from Northern direction and minimum (0.09 per m^2; 29.31 per 10 m radius) in the Eastern direction (Table 2). In terms of distance from the tree trunk towards end crown, maximum regeneration (0.23 per m^2; 73.27 per 10 m radius) was at 2m distance from the tree, followed by distance at 6m (0.17 per m^2; 52.33 per 10 m radius), and the lowest (0.02 per m^2; 5.23 per 10 m radius) at 8 m distance. Among the

Table 2. Natural regeneration of *Dalbergia lanceolaria* in the Vyara forest

Distance from tree	Direction									
	North		South		East		West		Overall mean	
	Recruit per m^2	Recruit in 10 m radius*	Recruit per m^2	Recruit in 10 m radius	Recruit per m^2	Recruit in 10 m radius	Recruit per m^2	Recruit in 10 m radius	Recruit per m^2	Recruit in 10 m radius
2m	0.27	83.73	0.33	104.67	0.20	62.80	0.13	41.87	0.23	73.27
4m	0.20	62.80	0.00	0.00	0.13	41.87	0.00	0.00	0.08	26.17
6m	0.13	41.87	0.13	41.87	0.13	41.87	0.27	83.73	0.17	52.33
8m	0.07	20.93	0.00	0.00	0.00	0.00	0.00	0.00	0.02	5.23
10m	0.00	0.00	0.13	41.87	0.00	0.00	0.13	41.87	0.07	20.93
Overall mean	0.13	41.87	0.12	37.68	0.09	29.31	0.11	33.49	0.11	35.59

*Extrapolate to 10 m radius (Crown area) = 314.16 m^2; regeneration count is from 15 trees

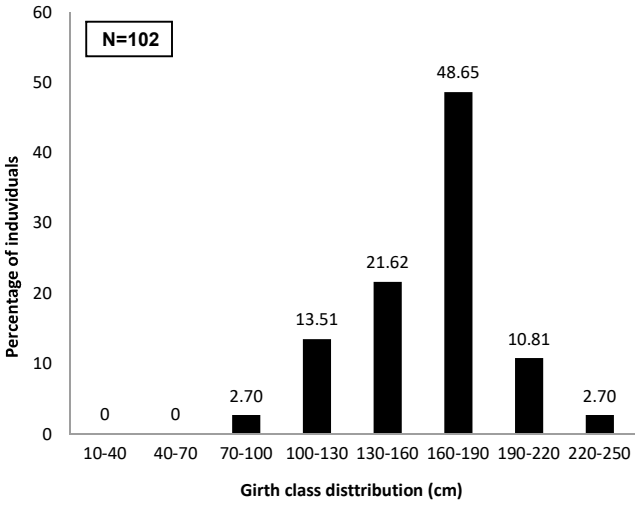

Fig. 1. Girth class distribution of *Dalbergia lanceolaria* in Vyara forest

regeneration, 27.41 per cent belonged to regeneration class IV followed by 26.47, 23.53 and 20.59 per cent of recruits belonged to I, II and III regeneration classes, respectively. The findings of the regeneration pattern are in line with the regeneration pattern of *Terminalia chebula* where maximum regeneration was encountered within 3 m distance from the tree and it reduced thereafter (Gunaga et al 2011, 2012). There is no clear decreasing trend of recruits from tree trunk towards end of the tree canopy. Being a light weight of pod, it was expected more regeneration towards tree canopy; however, the trend was reversed, where most recruits recorded near the tree, which could be due to root suckers, in contrast, recruits recorded near the edge of crown could be from seeds. The overall result showed that the natural regeneration count was poor (overall mean of 0.11 recruits per m^2 and 35.59 recruits per 10 m radius of crown). Seed-lots collected from tree are infested with seed pests in *D. lanceolaria* and that could be one of the reasons for poor germination, which may be associated with other few anthropogenic factors.

CONCLUSIONS

Study shows that with *Dalbergia lanceolaria* populations, species such as *Tectona grandis, Terminalia tomentosa*, *Madhuca longifolia* and *Garuga pinnata* are closely associated in terms of its presence, density, frequency, basal area and Importance value index. Demography and natural regeneration data of *D. lanceolaria* indicated that poor regeneration coupled with negligible number of trees in lower girth class may lead to threat of this species. Further, detailed study may be useful to address such issues as well as proper conservation/management plan to recuperate population of *D. lanceolaria*. Ecological data provided here could be useful for such action plan.

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AUTHORS CONTRIBUTIONS

M.S., L.K.B. -conceptualised the work; M.S., A. A.M., and D.N. -field data collection; S.M.P.-manuscript preperation.

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Seed and Pod Trait Variations in *Bauhinia vahlii* Wight & Arn. in Lower Himalayan Regions of Himachal Pradesh

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***Abstract*:** The present study was carried out at Dr. Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan during 2019-20. Five phenotypically superior genotypes of *Bauhinia vahlii* in four districts comprising of ten seed sources i.e. Nurpur , Dunera (district Kangra,), Rangas , Balduk ,Tauni devi (district Hamirpur), Kathar (district Sirmour), Kuthar ,Dharbanar, Ramshehar and Bhojnagar (district Solan) were selected with an aim to evaluate the seed sources on the basis morphological and floral characteristics, and seed traits. The maximum average leaf length (23.8 cm) was in Dunera and maximum average leaf breadth (19.9 cm) and average pod length (23.3 cm) was from Nurpur area collections. Bhojnagar seed source proved better for seed weight (136.9 g) and seed germination (91.11 per cent). High heritability (1.00) with high genetic advance (14.37) was recorded for germination and highest genetic gain was also for germination (28.10 per cent). The seed weight showed high and positive correlation with germination per cent (0.847).

***Keywords*:** *Bauhinia vahlii*, Floral, Morphological, Performance, Seed source

Bauhinia vahlii Wight & Arn. is a woody climber of Caesalpiniaceae family. The species takes the support of nearby trees to grow high and may rise upto 15-30 metres depending upon the size of the supporting trees in the forest. It is well distributed in the sub-Himalayan region ranging upto 1500 metres above mean sea level and also found in Assam, Central India, Bihar, Eastern and Western Ghats. In Himachal Pradesh, it is well distributed in Solan, Sirmour, Hamirpur and Kangra districts. The white coloured flowers of this species which are arranged as corymbose terminal racemes; begin to appear during April and may continue upto June thereby the entomophilous pollination takes place with the anthesis of floral buds (Kedarnath 1982). It can grow in variety of soils ranging from alkaline rocky soil and acidic but in well drained condition (Chauhan and Saklani 2013). This species is well established as medicinal woody climber and its various parts have medicinal uses such as leaves are used as demulcent, edible seed as tonic, bark for extracting tannins and leaves are even used as fodder and commercially used as donnas and pattals (Agarwal 2003).

MATERIAL AND METHODS

Seed sources: Survey was conducted from March 2019 to May 2019 in Himachal Pradesh for selection of seed sources and superior genotypes of *Bauhinia vahlii*. Total of 10 seed sources [Nurpur , Dunera (district Kangra,), Rangas, Balduk,Tauni devi (district Hamirpur), Kathar (district Sirmour), Kuthar, Dharbanar, Ramshehar and Bhojnagar (district Solan)] were identified and five best superior genotypes from each seed source were selected for fruit (pod) collection. From each genotype, seeds were collected from different positions and different directions of climber to avoid biasness of cross pollination. To ensure maximum genetic variation, source locations were at least 20 km apart from each other whereas selected climbers within location were at least 200 m apart from each other.

Experimental site: The present study was carried out at Dr. Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan, Himachal Pradesh, India which is situated at 31.3674°N, 77.3057°E at an elevation of 1290 m above mean sea level, with an average annual rainfall of 1500 mm.

Assessment of seed characters: Seeds from selected genotypes were collected in May, 2019 and were used to study variation in seed parameters *viz*., pod length, pod width, seed weight and seed colour. A total of 30 pods per genotype were used under study. Hundred seed weight and seed colour was recorded. Randomized block design was used with 3 replications for each pod and seed parameter.

Data analysis: Data collected were subjected to for statistically significance using SPSS software (SPSS 2006). Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) was calculated *Burton, 1952). Genetic advance and heritability (broad sense) were calculated (Lush 1940, Allard 1960, Panse and Sukhtame, 1978).

RESULTS AND DISCUSSION

Morphometric characteristics: The average mean values

of leaf morphometric characters are depicted in the Table 2, Figure 1. The maximum leaf length and leaf breadth was recorded in Dunera (23.8cm) and Nurpur (19.9cm) seed source, respectively whereas the maximum leaf area and leaf petiole length was in Tauni Devi (394.4cm^2) and Bhojnagar (10.6cm) seed source, respectively (Table 1, Fig. 2). Anand and Dwivedi (2014) have also observed leaf morpho-metric variations in *Bauhinia variegata* leaf .

Seed and pod characteristics: The fresh seed weight showed significant variation among seed sources with maximum of 136.9g in Bhojnagar seed source which showed potential to germinate in other areas as well (Table 3, Fig. 2). The results of seed weight are consistent with the findings of Mathur et al 1982. Nurpur seed source had maximum pod length of 23.3cm whereas Dharbanar seed source showed the maximum pod breadth of 5.88cm (Table 3). Considerable morphological and physiological variations between provenanes are reported elsewhere in other species (Singhdoha et al 2017)

Germination parameters: The seeds of *B. vahlii* were

Fig. 1. Leaf length and leaf breadth of *Bauhinia vahlii*

Fig. 2. Seeds selected among different seed sources

Table 1. Geographical locations of *B. vahlii* seed sources selected in the present study

Seed source	Code assigned	Locality covered	District	Altitude (m) (a.m.s.l)	Latitude	Longitude
Nurpur	S_1	Jawali	Kangra	478	32.1458° N	76.0115°E
Dunera	S_2	Katori Bangla	Kangra	550	32.4451° N	75.8912°E
Ramshahar	S_3	Ramshahar	Solan	815	31.0892° N	76.7957°E
Rangas	S_4	Jhaniari	Hamirpur	890	31.7112° N	76.4632°E
Balduk	S_5	Jolsapad	Hamirpur	900	31.690783° N	76.517715°E
Kuthar	S_6	Subathu	Solan	1065	30.9731° N	76.9672°E
Tauni Devi	S_7	Bhokhar	Hamirpur	1189	31.7144° N	76.5972°E
Kathar	S_8	Kathar	Sirmour	1480	30.7667° N	77.1442°E
Dharbanar	S_9	Dharbanar	Solan	1500	30.8294° N	77.0748°E
Bhojnagar	S_{10}	Bhojnagar	Solan	1502	30.891° N	77.17457°E

Table 2. Variation in leaf morphometric characters of *B. vahlii* among different seed sources

Seed source	Code	Leaf length (cm)	Leaf breadth (cm)	Leaf area (cm^2)	Petiole length (cm)
Nurpur	S_1	22.3	19.9	248.8	9.4
Dunera	S_2	23.8	18.3	326.0	7.0
Ramshahar	S_3	19.1	18.8	334.4	10.0
Rangas	S_4	22.8	19.3	345.0	9.6
Balduk	S_5	22.3	18.5	346.2	9.6
Kuthar	S_6	22.6	19.9	328.9	9.3
Tauni Devi	S_7	19.5	18.6	394.4	9.2
Kathar	S_8	23.4	19.7	366.8	8.5
Dharbanar	S_9	22.8	18.5	369.9	8.5
Bhojnagar	S_{10}	23.1	18.4	380.7	10.6
Mean		22.1	18.9	344.1	9.16
CD (p=0.05)		2.0	1.5	NS	1.5

cleaned, graded and sown in polybags under glass house conditions. The maximum germination percentage was recorded in S_{10} (Bhojnagar) seed source with the mean value of 91.11. While, germination energy (9.67) and germination value (23.91) were recorded maximum in Kuthar seed source (Table 4). The similar findings were recorded by Negi et al (2022) in pomegranate.

Genetic estimates: Genetic estimation is an important tool for evaluating data obtained from mother trees of different genotypes and half sib progenies after statistical analysis. Heritability, genetic gain and genetic advance are the major genetic parameters in tree improvement work. The highest Phenotypic Coefficient of Variation (PCV %) was recorded for germination energy (40.29) followed by germination value (35.19) whereas the lowest PCV was recorded for seed weight (9.03%) (Table 5). The highest Genotypic Coefficient of Variation (GCV %) was recorded for germination value (35.18), whereas the lowest GCV was recorded for seed weight (3.98%) followed by germination energy (5.62). These results are in general accordance with the findings of Showkat and Tyagi (2010) and Reni and Rao (2013). The results are also in agreement with the findings of Fakuta *et al*. (2015) where they found PCV was higher in proportion than GCV with respect to all the traits studied in *Acacia senegal*.

The results (Table 5) depicted high heritability (1.00) and genetic advance (14.37) for germination value whereas the highest genetic gain was recorded for germination % (28.10%). In forest trees similar findings were reported by Singh (2002) in full sib progenies of selected clones of Poplar (*Populus deltoides* Bartr.).

Correlation coefficient: Correlation is an important tool to

Table 3. Variation in seed and pod characteristics of *B. vahlii* among different seed sources

Seed source	Code	100 Seed weight (g)	Pod length (cm)	Pod breadth (cm)
Nurpur	S_1	113.4	23.3	5.62
Dunera	S_2	113.6	23.2	4.82
Ramshahar	S_3	121.7	19.3	4.76
Rangas	S_4	121.8	25.1	5.29
Balduk	S_5	130.6	21.2	4.86
Kuthar	S_6	121.0	22.0	4.97
Tauni Devi	S_7	124.8	17.6	4.83
Kathar	S_8	126.9	20.5	5.47
Dharbanar	S_9	132.4	21.2	5.88
Bhojnagar	S_{10}	136.9	22.7	5.19
Mean		124.3	21.62	5.17
CD (p=0.05)		17.3	NS	NS

Table 4. Variation in seed germination parameters of *B. vahlii* among different seed sources

Seed source	Code	Germination percentage (%)	Germination value	Germination energy
Nurpur	S_1	48.89	13.14	5.57
Dunera	S_2	53.33	15.53	8.29
Ramshahar	S_3	57.78	13.27	5.69
Rangas	S_4	75.56	12.34	5.33
Balduk	S_5	64.44	19.52	5.88
Kuthar	S_6	66.67	23.91	9.67
Tauni Devi	S_7	62.22	15.17	7.41
Kathar	S_8	68.89	18.49	6.17
Dharbanar	S_9	80.00	8.74	4.68
Bhojnagar	S_{10}	91.11	5.31	7.88
Mean		66.89	14.54	6.65
CD (p=0.05)		2.34	2.12	4.56

Table 5. Genetic estimates of *B. vahlii* leaf, pod, seed morpho-metric, and seed germination attributes

Character/parameter	Mean	Range	GCV	PCV	Heritability	Genetic advance	Genetic gain
Leaf length	22.1	19.1-23.8	6.41	8.35	0.59	2.25	10.15
Leaf breadth	18.9	18.3-19.9	2.03	5.16	0.15	0.31	1.65
Leaf area	344.1	248.8-394.4	9.26	15.64	0.35	38.87	11.29
Petiole length	9.16	7.0-10.6	9.22	13.50	0.46	1.18	12.94
100 Seed weight	124.3	113.4-136.9	3.98	9.03	0.19	4.49	3.61
Pod length	21.62	17.6-23.3	5.17	15.67	0.10	0.76	3.52
Pod breadth	5.17	4.76-5.88	5.44	10.51	0.26	0.30	5.81
Germination percentage	66.89	48.89-91.11	17.33	22.01	0.62	2.82	28.10
Germination value	14.54	5.31-23.91	35.18	35.19	1.00	14.37	21.47
Germination energy	6.65	4.68-9.67	5.62	40.29	0.02	0.10	1.61

Table 6. Simple correlation coefficient for leaf, pod, seed morpho-metric, and seed germination attributes of *B. vahlii*

Traits	SW	PL	PB	LL	LB	LA	PTL	GP	GV	GE
SW	1.000									
PL	-0.245	1.000								
PB	0.184	0.316	1.000							
LL	0.052	0.725*	0.441	1.000						
LB	-0.419	0.228	0.320	0.126	1.000					
LA	0.742*	-0.468	-0.151	-0.128	-0.530	1.000				
PTL	0.450	-0.060	-0.071	-0.402	0.102	0.083	1.000			
GP	0.847**	0.153	0.320	0.299	-0.258	0.666*	0.396	1.000		
GV	-0.377	-0.179	-0.401	-0.006	0.468	-0.191	-0.275	-0.498	1.000	
GE	-0.148	-0.016	-0.538	0.139	0.042	0.096	-0.120	-0.027	0.400	1.000

** = Highly significant at 1% level
* = Significant at 5% level
Where, SW= 100 seed weight, PL= pod length, PB= pod breadth, LL= leaf length, LB= leaf breadth, LA= leaf area, PTL= leaf petiole length, GP= germination percentage, GV= germination value, GE= germination energy index

measure the level of association between various characters. It plays an important role in tree improvement programmes as it helps in understanding the association among different characters whether one character is associated with the other character or not. The results computed in the Table 6 revealed that the seed weight gave highly positive correlation with germination percentage (0.847) and leaf area (0.742). The pod length gave highly positive correlation with leaf length (0.725). Leaf area gave highly positive correlation with germination percentage (0.666) at 1% level. The similar findings were reported by Divakara et al (2010) in *Pongamia pinnata*.

CONCLUSION

The present investigations were carried out for the evaluation of Toor (*Bauhinia vahlii*) seed sources. The leaf size is the most important character of economic importance of this species that are even used as fodder and commercially used as donas and pattals. The seed source namely Bhojnagar accounted for better seed traits among all the seed sources followed by Dharbanar seed source.

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Forest Governance, Forest Dependency, and Deforestation in Boxa Reserve Forest Area, Alipurduhar, North Bengal

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Abstract: About 300 million people live within or adjacent to dense forests and roughly 1.6 billion people depend on forest and forest products like food, fodder, fuelwood, and non-timber forest products. At the same time, high forest dependency harms the environment. The paper attempts to estimate forest dependency and to identify the factors affecting forest dependency. The study is based on primary data collected from the Buxa Forest Reserve Alipurduhar, North Bengal, during 2020-21. In the study, 6 villages and 151 households are selected randomly. The paper has utilized the forest governance index based on the FAOs indicators like the Rule of Law, Transparency, Accountability, Participation, Inclusive and Equitable, and Efficient and Effective. In addition, the paper has employed a beta regression model to estimate the impact of forest governance on forest dependence while the other socio-economic variables are treated as control variables. The forest dependence index and forest governance index of the households were 0.539 and 0.483 respectively. In addition, the study has identified timber broker nexus with forest officials and illegal extraction of forests backed by political intervention are the major sources of deforestation. The study revealed that good forest governance had a positive impact on forest dependency while socioeconomic variables like education and landholdings were negatively associated with forest dependency.

Keywords: Forest governance, Forest dependency, Non-timber forest products, Accountability, Participation, Beta regression

About 300 million people live within or adjacent to the dense forest (WWF 2019) and roughly 1.6 billion people depend on forest and forest products including food or fuel (Chao 2012, FAO 2020) and about 27 percent of household incomes derive from the forest (Angelsen et al 2014). Forests also provide global public goods like climate change mitigation, biodiversity, and carbon sequestration. The forest governance element like the control of corruption plays a leading role to enforce forest rules and regulations effectively for sustainable forest management (Banana et al 2014). The livelihood strategies are influenced by forest governance (Mustalahti et al 2012). In addition, governance has a strong link to forest conditions because of the existence of institutions that restrict forest use. There are three approaches for measuring forest dependency. The first approach is forest income (Rustin 2008, Wunder et al 2014). The second approach deals with livelihood or non-forest income forest dependency (Newton et al 2016, Basu 2020, Lauren et al 2020). The livelihood approach covers the use of forest products like fuel wood, food, fodder, and non-timber forest products as the measure of forest dependency (Sapkota and Odén 2008, Pandey 2010). The third is the socio-economic characteristics are the measure of forest dependency (Ntiyakunze 2021). The contribution of forest income is 22% of total household income across 17 developing countries while income lies between 14 and 20% in South America (Uberhuaga et al 2012). In the case of Asian and African countries, it varies from 10 to 20% and 30 to 45% of total household income respectively (Mukul et al 2016).

Some studies have focussed on the importance of Non-timber forest products (NTFPs) to the livelihood of people in Africa and Asian countries including India (Babulo et al 2008, Bwalya 2013). It is emphasized that forests act as safety nets for the rural poor in times of crisis due to drought. Besides, more literature has revealed that there is a nexus between forest dependence and forest-based poverty alleviation strategies (Nielsen et al 2012). The main objectives is to measure forest governance and forest dependency at the household level and identify the causes of deforestation including the impact of forest governance on forest dependency.

MATERIAL AND METHODS

Study area: The study was conducted in the Buxa Tiger Reserve, Alipurduar Forest division, situated in the district of Alipurduar, the Northern part of West Bengal. There are various ethnic tribes such as Rajbanshi, Santhals, Bodo and Toto, Oraons, etc. living in this district. The overall literacy rate is 64.7% of which the male literacy rate is 36.25% and the female rate is 28.47%. The major livelihood of the people is agriculture, tea garden labor, and forestry. This forest division is a combination of rivers, hills, tea gardens, and

forests. Forests cover of different districts of West Bengal is shown (Fig. 1). The study area has witnessed a declining trend in forest cover, reserved forest as well as protected forest (Table 1).

Sampling technique: The study utilizes primary data and data has been collected from the selected villages under Buxa Tiger Reserve in the Alipurduar Forest Divisions, during 2020-21. In the North Bengal forest division, we have taken one forest division like Alipurduhar purposively. In the Buxa Tiger Reserve forest area, we have selected 6 villages based on tribal population concentration. Once the villages are selected, 20% of households from each village are selected randomly. Total number of households consists of 151. Data have been collected by interview method based on the structured questionnaire.

Analytical Model

Forest dependency index: Forest dependency is measured by the forest dependence index (FDI) (Lauren et al 2020). There are four main indicators used for the formulation of forest governance index. They are Forest Collection Importance (FCI), Physical Asset (PA), Wealth (Wh), and Non-forest livelihood strategy (NFLS) (Basu 2021). The sub-indicators are selected in consultation with local elders, forest beat officers, and with literature review shown in Table 12. All sub-indicators have been normalized and such normalized score value takes 0 to 1. After normalization, we take the simple average of all sub-indicators to get forest dependency index.

Forest dependency index = $=\sum (FCI+PA+Wh+NFLS)/4$ (1)

The forest dependency index also lies between 0 and 1. Higher the index values represent higher forest dependency and vice-versa.

Forest governance index: Forest governance is measured by the forest governance index (FGI). FAO's governance has taken six main indicators like rule of law (RL), transparency (T), accountability (A), participation (P), inclusive and equitable (IE), and efficient and effective (EE). A description of main indicators along with the sub-indicators is presented in Table 11. All sub-indicators have been normalized and lies between 0 and 1. Then, simple averages of all sub-indicators are made. Once indices values of all sub-indicators are made can have separate indices of main indicators like indices of Rule of Law (RL), Transparency (T), Accountability (A), Participation (P), Inclusive and Equitable index (IE) and Efficient and Effective index (EE).

The overall forest governance index is measured by the averages of the Rule of Law index (RL), Transparency index (T), Accountability index (A), Participation index (P), Inclusive and Equitable index (IE), and Efficient and Effective index (EE). That is,

Forest Governance Index=$\sum (RL+T+A+P+IE+EE)/6$ (2)

The forest governance index lies between 0 and 1. Higher the index value of forest governance shows the indication of good forest governance and vice-versa.

Calculation of forest governance and forest dependency index of the sub-indicators and main indicators are presented in the Tables 11 and 12 respectively.

Model specification and estimation technique : To identify the factors affecting forest governance we apply the beta regression model. This model has been used because of the

Table 1. Trends of forest area, reserve forest and protected forests in Alipurduar forest division

Year	Forest area (ha)	Reserve forest (ha)	Protected forest (ha)
2009-10	179000	144300	16600
2013-14	179000	144300	16600
2018-19	106715	97503	9210

Source: District Survey Report, Govt. of West Bengal, 2021

Source: FSI 2020

Fig. 1. Forest cover in West Bengal

dependent variable say forest dependence index lies in the interval of (0, 1) (Das and Basu 2022).

Beta regression: Let y_1, y_2, y_3,--------y_n be the values of dependent variable and each y_i follows beta distribution with two parameters p and q . That is, B (p,q).

The beta regression model is given by

$$G(\mu_i) = ß_0 + ß_1 x_{i1} + ß_2 x_{i2} + ß_3 x_{i3+} ß_4 x_{i4+} ß_5 x_{i5+} ß_6 x_{i6+} = \eta_i,\ i = 1, n \quad (3)$$

Table 2. Distribution of sample households in Alipurduhar forest Divisions of West Bengal

Alipurduar Forest Division, North Bengal	
Alipurduar	
Village name	No. of households
Garobasti	26
Pampubasti	29
Rabhabasti	15
Santrabari	25
28 Basti	25
Jayanti	31
Total = 6	151

Source: Field survey

Here, η_i is the linear predictor for the ith observations and G(.) is the link function. The logit link is used in our study [G(μ) = log μ / 1- μ] for beta regression.

Where $x_{i1=}$Forest governance index

x_{i2} = Age of the head of household, x_{i3}= Educational index

x_{i4} = Caste of the head of the households

x_{i5}= Landholdings (in acre)

x_{i6} = % of forest income to total income (in INR),

y_i= Dependent variable = Forest dependency index

RESULTS AND DISCUSSION

The socio-economic condition of the sample households of the Alipurduar forest division are shown in Table 3. The sample households are dependent on the collection of NTFPs which include fuelwood, fodder, herbals, sal seeds and honey for their livelihood apart from agriculture and wage labour. About 78.81 percent of households collect fuelwood, followed by collection of mushroom, honey, fodder, herbals and others (Fig. 2).

The forest dependence index of the households is 0.539 (Table 4). The non-forest livelihood strategy index, wealth

Table 3. Socio-economic conditions of the sample households in the Alipurduar Forest Division

Socio-economic variables	Garobasti	Pampubasti	Rabhabasti	Santrabari	28 Basti	Jayanti	All
	N=26	N=29	N=15	N=25	N=25	N=31	N=151
Social status							
SC	3 (11.54)	3 (10.34)	2 (13.33)	2 (8)	1 (4)	7 (22.58)	18 (11.92)
ST	14 (53.85)	16 (55.17)	7 (46.67)	16 (64)	18 (72)	9 (29.03)	80 (52.98)
General	9 (34.62)	10 (34.48)	6 (40)	7 (28)	6 (24)	15 (48.39)	53 (35.10)
Gender							
Female	2 (7.69)	5 (17.24)	3 (20)	8 (32)	3 (12)	5 (16.13)	26 (17.22)
Male	24 (92.31)	24 (82.76)	12 (80)	17 (68)	22 (88)	26 (83.87)	125 (82.78)
Age of head of households							
21-40 years	11 (42.31)	18 (62.07)	6 (40)	10 (40)	14 (56)	7 (22.58)	66 (43.71)
41-60 years	10 (38.46)	8 (27.59)	8 (53.33)	13 (52)	10 (40)	19 (61.29)	68 (45.03)
above 60 years	5 (19.23)	3 (10.34)	1 (6.67)	2 (8)	1 (4)	5 (16.13)	17 (11.26)
Education							
Illiterate	10 (38.46)	6 (20.69)	7 (46.67)	8 (32)	10 (60)	9 (29.03)	50 (33.11)
Primary	5 (19.23)	9 (31.03)	2 (13.33)	8 (32)	4 (16)	5 (16.13)	33 (21.85)
Secondary	9 (34.62)	12 (41.38)	6 (40)	8 (32)	10 (40)	15 (48.39)	60 (39.74)
Above secondary	2 (7.69)	2 (6.90)	-	1 (4)	1 (4)	2 (48.39)	8 (5.30)
Average of family size	4.42	3.31	4.2	3.68	3.52	3.68	3.76
Economic status							
BPL	25 (96.15)	27 (93.10)	14 (93.33)	22 (88)	22 (88)	19 (61.29)	129 (85.43)
APL	1 (3.85)	2 (6.90)	1 (6.67)	3 (12)	3 (12)	12 (38.71)	22 (14.57)
Land holding (acre)							
Land less	1 (3.85)	-	-	-	-	15 (48.39)	16 (10.60)
<1 Acre	20 (76.92)	26 (89.66)	13 (86.67)	20 (80)	22 (88)	16 (51.61)	117 (77.48)
>= 1 Acre	5 (19.23)	3 (10.34)	2 (13.33)	5 (20)	3 (12)	-	18 (11.92)

Source: Field survey; Figures in parentheses show percentage of total households

index, forest collection importance index and physical asset index are 0.673, 0.538, 0.516, and 0.429 respectively. The households are classified into less forest dependence, moderate dependence and high dependence based on the values of forest dependence indices (Table 5). About 80 percent of households are highly forest dependent. The forest governance index in Alipurduar forest division is 0.483 (Table 6). The participation index value is highest followed by inclusive and equitable index and transparency index. The rule of law and efficient and effective indices are lowest compared to the other main indicators.

More than 95% of households expressed timber broker nexus with forest officials and 70 % of households expressed illegal forest extraction backed by political parties are responsible factors for deforestation in the Alipurduar forest division. About 72% of households pointed out that high forest dependency is not a responsible factor for deforestation (Table 7). The correlation matrix of the selected variables is calculated (Table 9). Since the dependent variable is forest dependency ranges in the interval of 0 to 1, beta regression is more appropriate to estimate the determinants of forest dependency. The estimates of beta regression model for Alipurduar forest division are presented in Table 10. The beta regression is run by adjusting heteroscedasticity.

Out of six independent variables included in the model, only four variables like forest governance index, educational index, landholdings, and percentage of forest income to total income are showing significant results. The model is overall significant as the LR Chi-square statistic is 103.77 (Table 10). The coefficient of the forest governance index is positive and significant. This means that forest dependency increases with the increase in forest governance. The increase in the forest dependency index shows there has been an increase in livelihood generation from forests. Thus, it also implies that good forest governance has a positive effect on the dependency vis-à-vis the livelihood generation of forest-

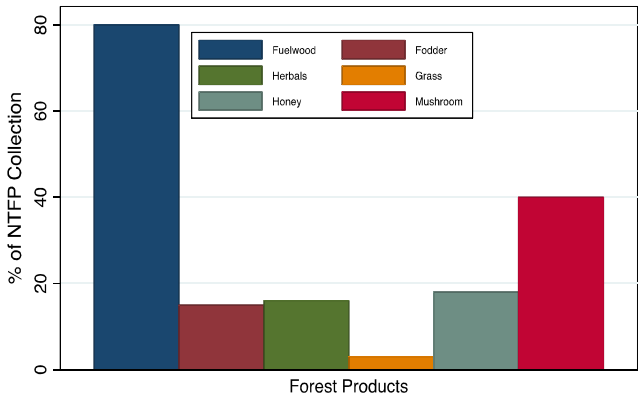

Fig. 2. Dependency on NTFPs in Alipurduar Forest Division

Table 4. Forest dependency index of households in the Alipurduar forest divisions in West Bengal

Forest dependence index	North Bengal
	Alipurduar
Forest collection importance index	0.516
Physical asset index	0.429
Wealth index	0.538
Non-forest livelihood strategies index	0.673
Forest dependency index	0.539

Table 5. Classification of forest dependent households in Alipurduar forest division

Forest dependency index	Assigned attribute	Households	
		Number	%
≤ 0.20	Less forest dependence	1	0.662
0.21-0.0.40	Moderate forest dependence	29	19.205
>0.40	High forest dependence	121	80.132

Table 6. Forest governance index across four forest divisions in South and North Bengal

Main indicator	Forest governance index
	Alipurduar
Rule of law index	0.172
Transparency index	0.545
Accountability index	0.385
Participation index	0.897
Inclusive and equitable index	0.775
Efficient and effective index	0.126
Governance index	0.483

Table 7. Causes of deforestation at the household level in Alipurduar forest division

Reasons for deforestation	Yes (=1)	No (=2)	Don't know (=3)
High forest dependency	37	109	5
Timber broker nexus with forest officials	144	3	4
Illegal extraction of forest due to political intervention	106	3	42

Table 8. Basic statistics for Alipurduhar forest division

Variables	Mean	S D
Forest governance index	0.483	0.100
Forest dependency index	0.538	.0118
Age (in years)	44.596	12.148
Educational index	0.283	0.156
Caste	2.231	0.647
Landholdings (in acres)	0.429	0.498
% of forest income to total income	7.838	

Table 9. Pair wise correlation coefficient matrix of the selected variables

	Forest governance index	Forest dependency index	Age	Educational index	Caste	Landholdings	% of forest income to total income
Forest governance index	1.0000						
Forest dependency index	0.1860*	1					
Age	-0.0822	-0.1062	1				
Educational index	0.0063	-0.0989	-0.0853	1			
Caste	0.0093	-0.0820	0.1332	-0.0220	1		
Landholdings	0.1629*	-0.1953*	-0.0940	0.0208	0.0289	1	
% of forest income to total income	0.1328	0.6266*	-0.1513	0.0663	0.0076	0.0486	1

*significant at 5% level

Table 10. Estimates of beta regression model for Alipurduar Forest Divisions, West Bengal

Independent variables	Dependent variable = Forest Dependence Index			
	Coefficient	SE	Z- values	P-values
Forest governance index	0.6632	0.2847	2.33	0.020
Age of head of households	- 0.0009	0.0023	-0.39	0.699
Educational index	-0.4360	0.1785	-2.44	0.015
Caste	-0.0616	0.0432	-1.43	0.154
Landholdings	-0.0252	0.0585	-4.31	0.000
Percentage of forest income to total income	0.0440	0.0042	10.33	0.000
Constant	-0.1180	0.1826	-0.06	0.948
		No. of observations = 151 LR Chi square (6) = 103.77 Prob > Chi square = 0.000 Log likelihood = 162.45		

dependent households. That is good governance helps to improve the livelihoods of the poor people who are forest dependent. This result is supported by the results in Nepal (WWF Nepal 2016). Education harms forest dependency. This means that the person with more education is less forest dependent. Higher education offers a lot of better employment opportunities compared to the forest sector. This result is consistent with the other studies (Fonta and Ayuk 2013, Baiyegunhi et al 2016). Similarly, the coefficient of land holdings is negatively associated with forest dependency. It seems to be the fact that high-holding farms have more opportunities for getting income from agriculture instead of depending on forests. Wen et al (2017) and Babulo et al (2009) also observed same trend. The coefficient of forest income to total income is positive and significant. This means that forest dependency increases with the increase in forest income and vice- versa. This further means that forest income has a positive impact on forest dependency. This result supports the result of Ntiyakunze (2021) in Tanzania.

CONCLUSION

The study concludes that there is poor socio-economic conditions of the households in the study area. More than 80% of households are small and marginal farmers, and 64% belong to ST and SC populations. More than 80% of households are living below the poverty line. More than 80% of households are highly forest-dependent and they depend on fuelwood, mushroom, honey, fodder, and herbals for livelihood generation. The forest dependence index (FDI) of the households in the forest division of Alipurduar is 0.539 and the forest governance index is 0.483. The participation index value is highest followed by the inclusive and equitable index and transparency index. The rule of law and efficient and effective indices are found to be the lowest compared to the other main indicators. The study has identified timber broker nexus with forest officials and illegal extraction of forests backed by political intervention are the major sources of deforestation and forest dependency is caused by forest governance, education, landholdings, and the percentage of forest income to total income. The paper calls for controlling illegal forest logging and strengthening the proper functioning of the institutions particularly the forest sector such that sustainable development of forests is ensured.

Table 11. Forest governance index for Alipurduar Forest divisions in West Bengal

Main indicators	Sub indicators		Alipurduar
Rule of law	Govt. rules regulating forest use		0.073
	Existence of any rule for use of forest product		0.349
	Encouragement for timber brokers for deforestation due to leakage in forest laws		0.149
	Weak forest administration leads deforestation		0.036
	Encouraging encroachers and illegal extraction due to political intervention		0.288
	Strong administration saves RF		0.139
			0.172
Transparency	Need of permission to collect/ harvest forest product		0.344
	If Y, do the users have to pay		0.629
	Issuance of permit by the correct authority		0.232
	Clearance of the agenda of the meeting		0.974
			0.545
Accountability	Regular presence in the meeting of the FPC		0.020
	Experience of conflict in last 5 years		0.974
	Obeying Govt rules by community members		0.162
			0.385
Participation	Planning index	Forest boundary demarcation	0.871
		Identifying forest users	0.868
		Participatory forest resource assessment	0.891
		Forest management committee election	0.921
		Encouraging others to participate	0.950
		Preparing forest management plan	0.914
		Developing forest management by laws	0.924
		Approval of forest management agreement	0.921
			0.907
	Implementation index	Reforestation of degraded forest areas	0.858
		Planting of fruit bearing trees such as mahua & mango	0.788
		Planting trees & management	0.669
		Nursery establishment	0.821
		Beekeeping	0.639
		Forest fire fighting	0.947
		Attending meetings	0.970
		Participations in knowledge & skill developing training	0.970
			0.833
	Monitoring index	Follow ups forest managements by law	0.964
		Forest patrols	0.921
		Reporting of illegal activities	0.967
		Supervise forest management plan implementation	0.937
		Forest boundary maintenance	0.970
			0.952
			0.897
Inclusive and equitable	SHG formation for female members		0.775
Efficient and effective	Changes in the availability of Wood & NTFP in last 5 years		0.185
	Poverty eradication programme reduce dependency on FPs		0.066
			0.126
Governance index			0.483

Source: Field survey data

Table 12. Forest Dependence Index (FDI) in Alipurduar forest division

Main index	Sub index	Value
Forest collection importance	Collected forest products	0.243
	Household dependent on forest	0.788
		0.516
Physical asset	Distance from home to forest	0.278
	Avg. time spend by HHs for collecting NTFP	0.334
	Household engage in collection NTFP	0.430
	Gender engage in collection NTFP	0.673
		0.429
Wealth	Total land holding including forest land	0.860
	Livestock	0.715
	Type of house	0.038
		0.538
Non forest livelihood strategies	Agricultural income	0.861
	Business income	0.895
	Service income	0.963
	Monthly wage	0.648
		0.673
FDI		0.539

Source: Field survey data

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Effect of Biopriming on Seed Germination, Growth and Biomass of Waras (*Heterophragma quadriloculare* Roxb.)

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***Abstract*:** Present investigation was undertaken during the year 2019-2020 at College of Forestry, Navsari Agricultural University, Navsari, Gujarat, India to ascertain effect of biopriming on seed germination, growth and biomass *Heterophragma quadriloculare*. The seed priming treatments comprised of application of Azotobactor, Potassium Mobilizing Bacteria: Pseudomonas Trichoderma 2 %, alone and in combination. Germination (%), survival (%), mean daily germination, peak value and germination value were not significantly influenced by different biopriming treatments. Significantly maximum plant height (30.18 cm), collar diameter (8.10 mm), number of leaves (28.46), fresh root weight (29.93 g plant^{-1}), dry root weight (9.85 g plant^{-1}), fresh shoot weight (24.45 g plant^{-1}) and dry shoot weight (10.12 g plant^{-1}) in response to with application of Azotobactor + KMB + PSB + Pseudomonas + Trichoderma 2 % (0.4 % Each)] followed by Azotobactor + PSB + KMB 2 % (0.66 % Each)] and the minimum was in control.

Keywords: Biopriming, Growth, Seed germination, Survival

Heterophragma quadriloculare Roxb. K. Schum belongs to Bignoniaceae and is a large deciduous tree endemic to Peninsular India. It is commonly known as Waras (Satani et al 2016). In India it is distributed in Western Deccan peninsulas and extremely rare in Bastar in Madhya Pradesh (Anonymous 2010). In Gujarat it is found in southern regions like Dangs, Vyara, Rajpipla, Vansda National Park, Waghai and Chhotaudepur of Gujarat. This species has less area of occupancy in the forests and in Gujarat state, it is listed in the vulnerable (VU) category. The plant is astringent, diuretic, and possesses antimicrobial, and anti-catarrhal properties. The plant contains a flavonoid glycoside, rutoside; coumarins, herniarin, umbelliferone and saponins. A related species, *H. hirsuta* L. is distributed in (Himalayas, from Kashmir to Kumaon up to 3000 m) and possesses Umbelliferone, scopoletin and herniarin (Khare 2007).

Bio-priming is a new technique of seed treatment that integrates biological (inoculation of seed with beneficial organism to protect seed) and physiological aspects (seed hydration) of disease control. It is recently used as an alternative method for controlling many seed and soil borne pathogens. It is an ecological approach using selected fungal antagonists against the soil and seed borne pathogens. Biological seed treatments may provide an alternative to chemical control. Seed priming is used as a tool to increase the speed and uniformity of germination and improve final growth. Therefore, seed priming alone or in combination with a low dosage of fungicides and/or biocontrol agents can be used to improve the rate and uniformity in the emergence of seed and reduce damping-off disease (Singh et al 2016).

Therefore, the current research aimed to investigate the effects of biopriming on seed germination, growth, and biomass of Waras (*H. quadriloculare*).

MATERIAL AND METHODS

The present investigation was carried out during the year 2019-20 at College of Forestry, Navsari Agricultural University, Navsari, Gujarat located 12 kilometers from the Arabian Sea coast at an elevation of roughly 11 above msl, at 20^{0}58' N latitude and 72^{0}54' E longitude. Completely Randomized Design was used as a statistical design to evaluate treatment effect. *H. quadriloculare* seeds were collected from natural population by the roadside of the Netrang to Rajpipla forest division in Gujarat. Pre-sowing soaking treatment was given to fresh seeds. Biopriming treatments were: T_1: Control, T_2: Azotobactor 2 %, T_3: Potassium Mobilizing Bacteria (KMB) 2 %, T_4: Phosphate Solubilizing Bacteria (PSB) 2 %, T_5: Pseudomonas 2 %, T_6: Trichoderma 2 %, T_7: Azotobactor + PSB + KMB 2 % (0.66 % Each), T_8: Pseudomonas + Trichoderma 2 % (1 % Each) and T_9 [Azotobactor + KMB + PSB + Pseudomonas + Trichoderma 2 % (0.40 % Each]. The seeds were mixed in respect to various treatments, then left at room temperature for six hours. Seeds were then sown into polybags @ 1 seed per polythene bag as per experimental details in the Net House Complex, College of Forestry, Navsari Agricultural

University, Navsari, Gujarat, India. The data was collected on seed germination (up to 30 days) and biomass (at 180 DAS) for further investigation.

RESULTS AND DISCUSSION

Germination attributes: The germination (%), survival (%), mean daily germination, peak value and germination value of *H. quadriloculare* was not significantly influenced by different bio primer treatments (Table 1).

Growth attributes: Growth and biomass parameters were significantly influenced by different bio primers. The plant height (30.18 cm), collar diameter (8.10 mm), number of leaves (28.46), fresh weight of root (29.93 g plant^{-1}), dry weight of root (9.85 g plant^{-1}), fresh weight of shoot (24.45 g plant^{-1}) and dry weight of shoot (10.12 g plant^{-1}) were significantly maximum in treatment T_9[Azotobactor + KMB + PSB + Pseudomonas + Trichoderma 2 % (0.40 % Each] (Table 2). The second-best treatment in order to response of different growth and biomass parameters was T_7-Azotobactor + PSB + KMB 2% (0.66 % each). This increase in seedling biomass production may be strongly correlated with improved accumulation of N and P due to AM fungi and PSB inoculation, respectively (Zambrano and Diaz 2008, Rathakrishnan et al 2004, Seema et al (2000). Maharana Rashmiprava et al (2018 a,b) observed that applying biofertilizers to *Gmelina arborea* seedlings at the nursery stage enhanced their fresh and dry biomass as well as the biomass of their individual sections (shoot, root, and leaves) in comparison to uninoculated seedlings.

The seed biopriming with *T. harzianum* treatment had the highest average seedling fresh and dry weight of the germinated seeds and was noticeably superior to the other treatments (Deshmukh et al 2016).

Seedling quality index (SQI) and seedling vigor index (SVI): The data in that the maximum seedling quality index (SQI) and seedling vigor index (SVI) was achieved (when plants were treated with Azotobactor + KMB + PSB + Pseudomonas + Trichoderma 2 % (0.40 % Each) 4.10 and 7321.13, respectively) followed by Azotobactor + PSB + KMB 2 % (0.66 % Each) (2.65 and 6528.00, respectively) (Fig. 1a & 1b).

Minimum SQI (1.27) and SVI (3478.13) were registered in response to Trichoderma 2 %, T_7: Azotobactor + PSB + KMB 2 % (0.66 % each) and control. It may be due to good establishment and adherence of bacteria on the seed before planting, so they can properly colonize the seed and affect these traits. The results are in line with Balasubramanian et al (2018), Moeinzadeh et al (2010), Ayswarya (2008).

Table 1. Effect of biopriming on germination attributes of *H. aquadriloculare*

Treatments	Germination (%)	Survival (%)	Mean daily germination	Peak value	Germination value
T_1	78.33	73.33	1.74	9.50	16.71
T_2	85.00	70.00	1.89	9.44	17.78
T_3	80.00	70.00	1.78	8.49	15.28
T_4	78.33	63.33	1.74	7.90	13.75
T_5	80.00	76.67	1.78	10.27	18.39
T_6	80.00	68.33	1.78	9.03	16.17
T_7	86.67	65.00	1.93	11.08	21.94
T_8	85.00	68.33	1.89	12.22	23.21

Table 2. Effect of biopriming on seedling growth and biomass attributes of *H. aquadriloculare*

Treatments	Plant height (cm)	Collar diameter (mm)	Number of leaves/plant (mm)	Root fresh weight (g/plant)	Shoot fresh weight (g/plant)	Root dry weight (g/plant)	Shoot dry weight (g/plant)
T_1	15.08	6.26	12.16	9.84	7.98	2.82	2.50
T_2	21.50	7.07	21.03	17.76	14.90	4.69	4.44
T_3	20.68	6.99	19.61	16.83	14.45	4.15	4.40
T_4	20.39	6.78	20.45	15.75	11.85	4.09	4.20
T_5	20.35	6.43	17.61	14.51	10.76	3.57	3.04
T_6	21.70	6.32	11.79	13.61	8.59	3.01	2.76
T_7	20.50	7.21	26.63	22.02	17.98	5.40	5.19
T_8	20.29	6.50	14.84	14.48	11.60	3.81	3.51

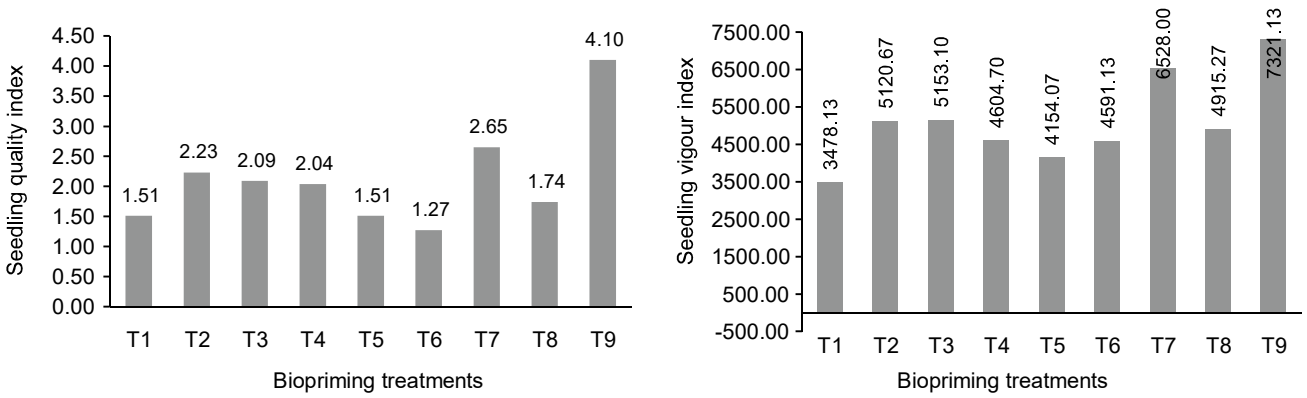

Fig. 1. Effect of biopriming on seedling quality index and seedling vigor index of *H. aquadriloculare*

CONCLUSION

Different bioprimer treatments applied singly or in combination with one or more other bioprimers improved the species growth and biomass metrics. Compared to controls, each bioprimer improved the growth and biomass indices. However, none of the different bioprimers had a substantial impact on the germination characteristics. Individually applied bioprimers produced a noticeable improvement over the control. However, when compared to control, the combination of the various bioprimers, namely Azotobactor + KMB + PSB + Pseudomonas + Trichoderma 2% (0.40% Each), produced the best outcomes for the plants' growth, biomass, and vigour indices. For this reason, a variety of bioprimers can be combined to create high-quality seedlings in forest nurseries that will support the conservationist approach.

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Development of Volumetric Equation and Volume Table for *Casuarina* Species

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Abstract**:** *Casuarina* is one of the multipurpose tree species grown in different parts of the country. In the present study, 1108 casuarina trees were selected in 12 different diameter classes from D_1 (10 to 45 cm) to D_2 (45 to 70 cm). The whole data set was divided into two *viz.,* 10 to 45 cm and 45 to 70 cm to obtain precision equation. The calculated volume and HD^2 Index was used in regression equation. The volumetric equation (V_1) = 0.00005 x HD^2 + 0.0196 can be used to assess the volume of standing *Casuarina* trees having 10 to 45 cm DBH; whereas, for higher diameter classes, *i.e.,* trees having 45 to 70 cm DBH, equation V_2 = 0.00003 x HD^2 + 0.6874 can be used. For farmers point of view, volume table was developed using these two formulae for easy understanding and quick estimation. Further, foresters, wood merchants, wood industrial persons can also utilize these volumetric equations as well as volume table for estimating tree volume.

Keywords**:** *Casuarina* species, Growth, Volume, Regression equation, Volume table

Casuarina equisetifolia L. (Family Casuarinaceae) is widely planted throughout the tropics, especially to provide timber whilst growing on poor sandy soils near the coast and thus also providing shelter and protection for the soil. The tree fixes atmospheric nitrogen and is able to grow vigorously on barren, polluted sites and thrive in deep sandy soils. It is therefore often planted for reclaiming and improving the land (Nicodemus 2009). The wood is used for house posts, rafters, electric poles, tool handles, oars, wagon wheels and mine props. The wood is used to produce paper pulp using neutral sulphate and semi-chemical processes, and as a raw material for rayon fibres. Calorific value of the wood is about 5,000 kcal/kg and wood ignite readily even when it green, and ashes retain heat for longer periods; moreover, it produces high quality charcoal (Warrier et al 2014). It is estimated that about 500,000 ha are planted with Casuarina in the coastal states of Andhra Pradesh, Orissa, Tamil Nadu and the Union Territory of Puducherry (Nicodemus 2009). Therefore, it is one of the commercial multipurpose tree species suitable for growing in different land use systems including agroforestry, avenue tree, green belts (Nicodemus 2009, Gurumurthi and Subramanian 1998).

Casuarina equisetifolia and *C. junghuhniana* are commercial exotic tree species introduced to India and is grown in different ecological conditions (Amanulla et al 2001, Warrier et al 2014). In the beginning, species was introduced mainly to the coastal belt of different places. Even, old casuarina plantations are still maintained near the sea-coasts in different parts. Due to its pulpwood quality, genetic evaluation has been carried out in different parts of the country. At present, fast growing genotypes/clones and hybrids of *Casuarina equisetifolia x C. junghuhniana* are also planted in different parts of the country and farmers are gaining more yield and higher economic returns from this crop (Amanulla et al 2001, Nicodemus 2009). It is remarkably well suited for boundary planting and shows promise as an agroforestry species for arid and semi-arid areas. Due to its fast-growing nature and local demand for pole and pulpwood, Gujarat farmers are growing this plant in their farmlands. Further, local industries *viz.,* paper industries (for pulp wood) and construction industries (for pole) are procuring raw materials from the farm field. The present study focused towards development of volumetric equation and constructing volume table for this species. This information is helpful for farmers, wood merchants and foresters and industrial staff to quickly asses the volume of standing trees.

MATERIAL AND METHODS

The present study was carried out in different parts of south Gujarat (Agro-ecological zone, *i.e.,* Heavy rainfall zone AES-III), India. In order to develop volumetric equation and volume table, Casuarina trees belonged to different diameter classes *viz.,* D1: 10-15 cm, D2: 15-20 cm, D3: 20-25 cm, D4: 25-30 cm, D5: 30-35 cm, D6: 35-40 cm, D7: 40-45 cm, D8: 45-50 cm, D9: 50-55 cm, D10: 55-60 cm, D11: 60-65 cm and D12: 65-70 cm, were considered and various biometric parameters such as tree height (m), DBH (cm), Mid- diameter (cm), clear bole height (m) and crown height (m) were recorded. Further, using these data base, Form Quotient and

Volume (m^3) of standing trees were estimated (Gunaga et al 2021). Trees located in the conventional plantation, coastal belt, avenue/road-side plantation, agroforestry landscape were used. After compiling all the database and arrangement, data were subjected to statistical analysis and volumetric equation was developed using regression equation following standard method.

RESULTS AND DISCUSSION

In the present study, about 1300 trees belonged to different diameter classes from D1: 10-15 cm to D12: 65-70 cm were selected in different parts of south Gujarat including trees established in and around the NAU campus, and coastal belts. After processing the data, some of the out-layer trees were removed from the data base and total 1108 trees of 12 different diameter classes were used for assessment (Table 1). The quotient [FQ=DBH/MD] and volume [$V=\pi D^2/4$ x H x FQ] were estimated using selected 1108 trees. The overall mean clear bole height and crown length recorded in different diameter classes (Fig. 1). The data were subjected to regression equation as per standard statistical procedure and volumetric equation were developed (Table 2). The overall growth showed that diameter increased with increase in the height and the overall tapering was 0.6 (FQ) among sampled trees. For estimation of volumetric equation, index of HD^2 (Height, H x Diameter^2, D^2) was calculated using individual tree height and respective diameter. Then, this data was used along with estimated volume using regression equation with linear model (Fig. 2). The data of volume and HD^2 Index of all the trees belonged to 12 diameter classes were used to fit volumetric equation using regression model and the following equation was developed.

$V = 0.00004 \times HD^2 + 0.1446$ ($R^2 = 0.932$) ---------- Type-1

Where, V is volume (m^3), H is tree height (m), D is DBH (cm) and 0.1446 is constant value

There was a huge difference at lower diameter classes by comparing original calculated volume with equation type-1. Therefore, to reduce the error, data were split into two large data sets. The first set of data from diameter classes D1 to D7 were used for estimation of separate volume and the second set of data belonged to diameter classes- D8 to D12 were used for estimation of volume. Regression equations developed using first data set (D1 to D7 *i.e.,* 10 to 45 cm; Fig. 2a) and second data set (D8 to D12 *i.e.,* 45 to 70 cm; Fig. 2b) are given as Type-2 and Type-3, respectively and volumetric equations are given below:

$V_1 = 0.00005 \times HD^2 + 0.0196$ ($R^2 = 0.919$) ---------- Type-2

where 0.0196 is constant value

$V_2 = 0.00003 \times HD^2 + 0.6874$ ($R^2 = 0.712$)---------- Type-3

where 0.6874 is constant value

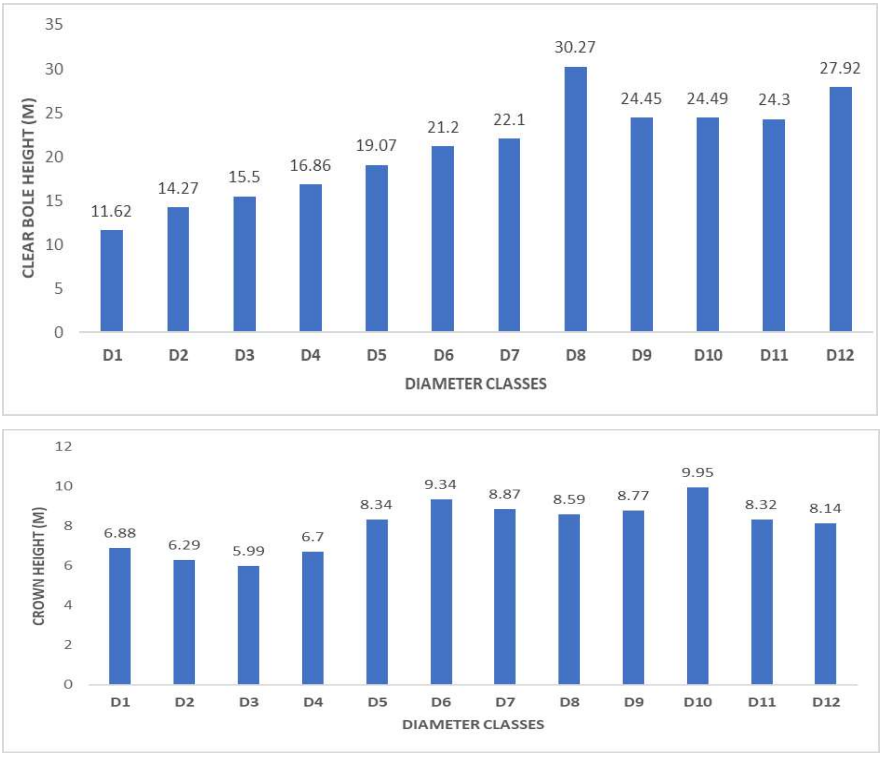

Fig. 1. Average clear bole height and crown height of *Casuarina* trees across different dimeter classes (N=1108)

Estimated values using Type-1, Type-2 and Type-3 volumetric equations were validated with actual volume [$V=\pi D^2/4 \times H \times FQ$] calculated using field data. Result showed that, among three volumetric equations, Type 2 and Type 3 showed better comparison than Type 1. Therefore, Type-2, volumetric equation estimated using $V_1 = 0.00005 \times HD^2 + 0.0196$ can be used for estimating volume of standing *Casuarina* trees belonged to 10 to 45 cm DBH. Furthermore, for *Casuarina* trees having 45 to 70 cm DBH, volumetric equation estimated using $V_2 = 0.00003 \times HD^2 + 0.6874$ can be used. Furthermore, by using these formulae, volume table was constructed with different diameter and height ranges

Table 1. Biometric parameters of standing *Casuarina* trees across different diameter classes

Diameter classes		Sample size (N)	DBH (cm)	Mid-dia. (cm)	Height (m)	FQ	Volume (m^3)
D1: 10 to 15 cm	Min	173	10.25	5.40	8.40	0.09	0.01
	Max		15.00	14.90	27.30	1.05	0.39
	Mean		12.68	9.13	16.54	0.71	0.16
D2: 15 to 20 cm	Min	132	15.10	8.20	10.50	0.51	0.14
	Max		20.00	17.30	29.20	0.94	0.63
	Mean		17.69	12.25	20.39	0.69	0.35
D3: 20 to 25 cm	Min	169	20.05	10.30	13.70	0.47	0.28
	Max		25.00	20.80	30.80	0.95	1.18
	Mean		22.75	14.29	21.81	0.63	0.56
D4: 25 to 30 cm	Min	180	25.05	12.60	15.20	0.46	0.41
	Max		29.95	22.10	33.10	0.82	1.50
	Mean		27.44	16.21	23.74	0.59	0.84
D5: 30 to 35 cm	Min	144	30.10	13.10	17.20	0.42	0.64
	Max		34.95	28.50	40.50	0.88	2.93
	Mean		32.48	18.72	26.54	0.58	1.29
D6: 35 to 40 cm	Min	129	35.05	14.80	19.70	0.40	0.94
	Max		40.00	37.50	41.50	1.00	4.56
	Mean		37.53	22.03	29.49	0.59	1.95
D7: 40 to 45 cm	Min	73	40.10	15.80	18.30	0.37	0.97
	Max		45.00	36.60	41.30	0.85	4.10
	Mean		42.49	23.52	30.42	0.55	2.42
D8: 45 to 50 cm	Min	40	45.05	19.50	26.20	0.40	2.16
	Max		49.85	33.40	45.50	0.74	5.54
	Mean		47.35	25.31	33.71	0.53	3.20
D9: 50 to 55 cm	Min	27	50.60	20.60	26.30	0.39	2.23
	Max		54.95	36.70	43.30	0.67	6.80
	Mean		52.98	27.54	32.56	0.52	3.76
D10: 55 to 60 cm	Min	21	55.40	20.50	27.10	0.35	2.80
	Max		59.95	38.10	45.10	0.66	7.11
	Mean		57.63	28.40	34.33	0.49	4.45
D11: 60 to 65 cm	Min	11	60.30	20.70	27.40	0.34	2.88
	Max		64.75	35.40	43.30	0.56	7.65
	Mean		62.23	27.17	33.93	0.44	4.58
D12: 65 to 70 cm	Min	9	65.95	23.70	31.10	0.36	4.30
	Max		69.50	31.30	41.70	0.45	7.11
	Mean		67.79	27.97	36.66	0.41	5.48
Total		1108					

DBH=Diameter at breast height; FQ= Form Quotient

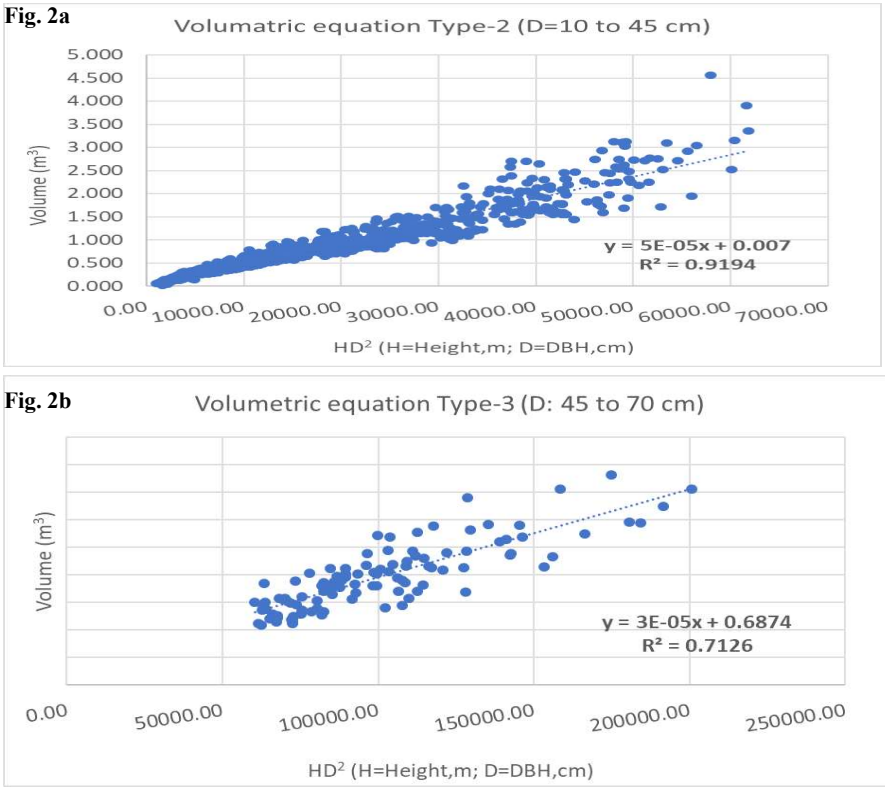

Fig. 2. Regression equations developed using HD^2 values for assesment of volume of standing Casuarina trees (2a- Trees having 10-45 cm DBH; 2b- Trees having 45-75 cm DBH)

Table 2. Details of volumetric model estimated using HD^2 and regression statistical parameters in *Casuarina* sp

Formula type model form	Sample size (N)	Regression constant (a)	Regression coefficient (b)	Multiple R	R^2	Adjusted R^2	SE (±)	F value	Sign. level
Type-2 Y= a+ b HD^2	1000	0.0196	0.00005	0.962	0.925	0.925	0.216	12339.91	<0.001
Type-3 Y= a+ b HD^2	108	0.6874	0.00003	0.844	0.712	0.709	0.646	262.80	<0.001

Table 3. Local volume table developed for Saru (*C. equisetifolia*) trees

DBH (cm) (Dia. range and mid value)	Mid height/ Mid diameter	Height in m (Height range and mid value)											
		8-11	11-14	14-17	17-20	20-23	23-26	26-32	32-35	35-38	38-41	41-44	44-47
		9.5 m	12.5 m	15.5 m	18.5 m	21.5 m	24.5 m	27.5 m	33.5 m	36.5 m	39.5 m	42.5 m	45.5 m
Volume for trees having diameter (DBH) of 10 cm to 45 cm													
10-15	12.5 cm	0.094	0.117	0.141	0.164	0.188	0.211	0.234					
15-20	17.5 cm	0.165	0.211	0.257	0.303	0.349	0.395	0.441					
20-25	22.5 cm		0.336	0.412	0.488	0.564	0.640	0.716	0.868				
25-30	27.5 cm			0.606	0.719	0.833	0.946	1.059	1.286				
30-35	32.5 cm				0.997	1.155	1.314	1.472	1.789	1.947	2.106	2.264	2.423
35-40	37.5 cm				1.320	1.531	1.742	1.953	2.375	2.586	2.797	3.008	3.219
40-45	42.5 cm				1.690	1.961	2.232	2.503	3.045	3.316	3.587	3.858	4.129
Volume for trees having diameter (DBH) of 45 -70 cm													
45-50	47.5 cm						2.346	2.549	2.955	3.158	3.361	3.564	3.767
50-55	52.5 cm						2.713	2.961	3.457	3.705	3.954	4.202	4.450
55-60	57.5 cm							3.415	4.010	4.308	4.605	4.903	5.200
60-65	62.5 cm							3.910	4.613	4.965	5.316	5.668	6.019
65-70	67.5 cm								5.266	5.676	6.087	6.497	6.907

(Table 3). Efforts were also made to develop volumetric and biomass equation among different tree species including *Casuarina* (Segura and Kanninen 2005, Tewari and Singh 2006, Warrier et al 2014, Thakur et al 2021). Yield table for stem wood of *Casuarina equisetifolia* (kg tree^{-1}) was worked out using volumetric equation, where HD^2 values are used at the time development of regression equation (Warrier et al 2014). In fact, data on predicted volume can also be used for assessment of tree biomass and yield table across different diameter classes (Dash et al 1999, Vidyasagaran and Paramathma 2014).

CONCLUSION

The regression analysis revealed that standing Casuarina trees can be estimated using following equations for different diameter classes *viz.,* $V_1 = 0.00005 \times HD^2 + 0.0196$ for trees having 10 to 45 cm DBH, and $V_2 = 0.00003 \times HD^2 + 0.6874$ for trees having 45 to 70 cm DBH. Therefore, farmers, foresters, wood merchants, wood industrial persons can utilize these volumetric equations for quick estimating volume of standing *Casuarina* trees.

AUTHORS CONTRIBUTION

Dr. A.A. Mehta and Dr. N.S. Thakur (Co-PI of this technical Programme) helped in technical aspects, Dr. Y.A. Garde, as Statistician helped in analyzing the data; J.B. Bhusara and R.L. Sondarva are SRFs and helped in field data collection

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Influence of Biofertilizers on Seedling Growth and Vigour of Indian Redwood [*Soymida febrifuga* Roxb.]-A Lesser Known Tree Species

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Abstract: *Soymida febrifuga* popularly called as Indian Redwood, is one of the lesser known tree species distributed naturally in the deciduous forests. Through the research project, some population of this species are identified in different forests of South Gujarat. Its occurrence is found to be random and less dense with poor natural regeneration. In the present study, influence of biofertilizers on growth and vigour of Indian redwood seedlings were assessed in the nursery. A nursery experiment consisting of twenty-two treatments of six biofertilizers *viz*. Azotobacter, Azospirillum, Acetobacter, PSB, Pseudomonas and VAM in single and combinations including control, which were kept by following completely randomized design. Result shows that single and combination of biofertilizers treatments significantly influenced the seedling growth and vigour parameters in the seedlings of Indian redwood. Among them, seedlings treated with Azospirillum-PSB combination *i.e.,* Azospirillum @ 5ml plant^{-1} + PSB @ 5ml plant^{-1} treatment, recorded the maximum seedling height (16.01 cm), collar diameter (4.90 mm), total leaf area (469.43 cm^2), fresh weight (17.66 g) and dry weight of seedlings (3.78 g) along with seedling quality index (0.75) after the age of six months over control and many other treatments. Therefore, this treatment is suggested for production of good quality seedlings Indian redwood in large quantity in nursery.

Keywords: Biofertilizer, Indian redwood, Nursery growth, Seedling vigour

Soymida febrifuga (Roxb.), popularly known as Indian Redwood, belongs to the family Meliaceae and is confined only to India and Sri Lanka (Hooker 1982). In India, it is distributed in the hilly districts of north, western, central and southern India, which extends to Travencore (Hooker 1982). Occasionally, it is found in mixed deciduous forest on Aravalli hill slopes and its outliers in Rajasthan and its presence is also well documented in deciduous forests of Maharashtra (Singh and Karthikeyan 2000), Uttar Pradesh, Bihar, Odisha, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala (Sharma et al 1993); whereas, in Gujarat, it is rarely seen in the districts of Dangs, Vyara, Rajpipla regions of South Gujarat as well as Chhotaudepur and Panchmahals area of Central Gujarat and some other parts of Saurashtra region (Shah 1978). Due to non scientific and over extraction of bark the population of old trees has been declining and kept in the status of Near Threatened regional basis in Gujarat (Anonymous 2008).

Indian Redwood, is a very slow growing species, approximately 2.5 to 5 cm height of seedlings attains in the first year in its natural habitat (Bhide et al 2016, Sandhya and Birader 2015 and Sukhadiya et al 2019). As a part of research project, some population of this species were identified in different forests of South Gujarat. Its occurrence is random, occasionally clumped having less dense population with poor natural regeneration. Indian Redwood reach up to the height of 30 m with girth of 2.5 to 3.0 m. It has rough bark that exfoliates in scales. Seed germination is found to be less than 30%; however, Prajapati (2021) reported that the germination of this species can improve upto about 52 % than control 35% by varying germination media. Viability of seeds of Indian redwood decreases with the increase of storage period (Ashalatha and Thejaswini 2015).

Considering utilization of this species, the dark brown heartwood is hard and durable, which is used in house building as posts, rafters and beams, for well work, plough shares, furniture, pestles and pounders. It is also well suited for carving and turnery, wooden flooring, for making furniture for frames and stiles and for framing lighter coloured paneling (Sukhadiya et al 2019). Bark is used in tanning and tanned leathers possess good colour, good feel and fullness. Bark is used in ayurvedic medicine and it has the characteristics of acrid, refrigerant, anthelmintic, aphrodisiac, laxative, good for sore throat and it removes “vata” cures “tridosha” fevers, cough, asthma, it also removes blood impurities and good for ulcers, leprosy, dysentery (Kirtikar and Basu 2003). Moreover, the bark is useful as an anticancer remedy, for blood coagulation, wounds, dental diseases, uterine bleeding and hemorrhage (Chiruvella et al 2010).

By looking into the usage of species and its natural occurrence and being lesser known species, the use of this species for large scale plantation in different land-use systems is necessary. Further, this species could be one for the programme of ToF (Trees Outside Forests) for plantation establishment and increasing the green cover. Thus, the present experiment was undertaken to understand the influence of biofertilizers on early growth and vigour of seedlings in Indian redwood (*Soymida febrifuga*).

MATERIAL AND METHODS

The present investigation was conducted during the year 2021-22 in College of Forestry, Navsari Agricultural University (NAU), Navsari, Gujarat, India. Mature fruits of Indian redwood were collected from the middle-aged trees distributed in Amania range of Vyara forest division (South Gujarat). Fruits were dried under shade for seven days to crack down the pericarp. After capsule break open, seeds were collected, processed and stored properly . Seeds were sown in germination trays containing soil and sand (1:1). Germinated seedlings of two leaf stage were transferred into polythene bags of size 6 x 8 inch having common growing media of Soil: Sand: FYM (2:1:1). The transplanted seedlings were arranged in CRD (Completely Randomized Design) consisting of three repetitions and twenty two treatments *viz.,* T_1:Control (No biofertilizer), T_2:Azotobacter @ 10 ml plant^{-1}, T_3:Azospirillum @ 10 ml plant^{-1}, T_4:Acetobacter @ 10 ml plant^{-1},T_5:PSB @ 10 ml plant^{-1}, T_6:Pseudomonas @ 10 ml plant^{-1}, T_7:VAM @10ml plant^{-1}, T_8:Azotobacter @ 5ml plant^{-1} + Azospirillum @ 5ml plant^{-1}, T_9:Azotobacter @ 5ml plant^{-1} + Acetobacter @ 5ml plant^{-1}, T_{10}:Azotobacter @ 5ml plant^{-1} + PSB @ 5ml plant^{-1}, T_{11}:Azotobacter @ 5ml plant^{-1} + Pseudomonas @ 5ml plant^{-1}, T_{12}:Azotobacter @ 5ml plant^{-1} + VAM @ 5ml plant^{-1} , T_{13}:Azospirillum @ 5ml plant^{-1} + Acetobacter @ 5ml plant^{-1} , T_{14}:Azospirillum @ 5ml plant^{-1} + PSB @ 5ml plant^{-1}, T_{15}:Azospirillum @ 5ml plant^{-1} + Pseudomonas @ 5ml plant^{-1}, T_{16}:Azospirillum @ 5ml plant^{-1} + VAM @ 5ml plant^{-1} , T_{17}:Acetobacter @ 5ml plant^{-1} + PSB @ 5ml plant^{-1}, T_{18}:Acetobacter @ 5ml plant^{-1} + Pseudomonas @ 5ml plant^{-1}, T_{19}:Acetobacter @ 5ml plant^{-1}+ VAM @ 5ml plant^{-1}, T_{20}:PSB @ 5ml plant^{-1}+ Pseudomonas @ 5ml plant^{-1}, T_{21}:PSB @ 5ml plant^{-1} + VAM @ 5ml plant^{-1} and T_{22}:Pseudomonas @ 5ml plant^{-1}+ VAM @ 5ml plant^{-1}.

The biofertilizers were applied @ 10 ml/seedling after establishment of transplanted seedlings. Various growth parameters such as seedling height, collar diameter, number of leaves per seedling, total leaf area per seedling, root length, fresh and dry weight of plant were recorded after 180 DAT (Days After imposing Treatment). Further, the seedling vigour indices such as root to shoot ratio, sturdiness quotient and seedling quality index (Dickson et al 1960) were calculated. The data obtained from the experiment were processed and fed to the data sheet in MS Excel and subjected to statistical analysis using DOS based software developed by Department of Agricultural Statistics, NAU, Navsari by following CRD (Panse and Sukatme 1985).

RESULTS AND DISCUSSION

There was significant variation among 21 treatments of biofertilizers (single and combination) with control ($P< 0.05$) (Table 1 and Figure 1). The height of seedling varied from 11.57 cm (T_1) to 16.01 cm (T_{14}) with overall mean of 13.07 cm; while seedling collar diameter varied from 2.83 mm (T_1) to 4.90 mm (T_{14}) with overall mean of 3.99 mm (Table 1). Similarly, significant variation was also recorded among various biofertilizer treatments for seedling dry biomass, which ranged from 1.15 g (T_1) to 3.78 g (T_{14}) with mean of 2.07 g.

Among all the biofertilizer treatments, seedlings of *S. febrifuga* treated with Azospirillum @ 5ml plant^{-1} + PSB @ 5ml plant^{-1} treatment (T_{14}) achieved significantly maximum shoot length (16.01 cm) and collar diameter (4.90 mm). Moreover, this treatment (T_{14}) also enhanced the total leaf area (469.43 cm^2), which was statistically at par with Azotobacter @ 5ml plant^{-1} + Acetobacter @ 5ml plant^{-1} (T_9) at 180 DAT. Further, maximum root length (20.28 cm) was recorded in seedling treated with Azotobacter @ 5 ml plant^{-1} + Azospirillum @ 5 ml plant^{-1} (T_8), which was followed by T_{21}. In fact, seedlings exposed to T_{14} also showed significantly higher fresh (17.66 g) and dry weight of plant (3.78 g; Table 1).

Most of the growth parameters of *S. febrifuga* seedlings were more effective in combination treatments of biofertilizers as compared to single application and than control (Table 1). The combination biofertilizer treatments enhanced the growth attributes and it may be due to the synergistic effect with each other along with the host plant. The growth of seedlings in early stages in nursery normally depends upon the tree species and its growth characteristics, growing media and its types, nature along with the types of inoculants or biofertilizers applied (Chauhan 2020). Normally, certain biofertilizers enhanced the growth of seedlings due to their symbiotic and positive interaction with the seedlings (Duponnoisa et al 2005 and Wu et al 2010). Moreover, increment in growth attributes of seedlings might be due to increased cell elongation and cell multiplication coupled with enhanced nutrient uptake by plants due to biofertilizer inoculation (Vijayakumari and Janardhanan 2004). Azospirillum in the soil media, helps in enhancing the nutrient and water uptake capacity which are necessary for better growth and assists in maintenance of good physical

and chemical properties of the media (Chiranjeevi et al 2018); moreover, the increase of growth may be attributed to high accumulation of chlorophyll and protein in the plant tissue by the application of nitrogen fixing bacteria of the genus *Azospirillum* (Mohan and Rajendran 2017 and Rajendran 2012). Further, phosphate solubilizing bacteria (PSB) can convert the insoluble phosphates into plant available forms and can also promote plant growth via producing hormones, such as cytokinin and indole acetic acid (Wu et al 2010) which helps in increasing the growth and also attributed to the increase in P uptake in shoots of the seedling (Jangandi et al 2017). Therefore, these two combinations are most important in producing quality seedlings in forest tree species. Such influence was also noticed in the present study, where the combination of Azospirillum @ 5ml plant^{-1} + PSB @ 5ml plant^{-1}treatment (T_{14}) resulted in significant increase in seedling growth attributes (Table 1), where combine application of Azospirillum and PSB could made synergistic effect of enhanced seedling growth in *S. febrifuga.* Such inference also reported in other tree species like *Gmelina arborea* (Maharana et al 2018) and *Aegle marmelos* (Mohan and Rajendran 2017).

Apart from growth parameters, various vigour indices like root: shoot ratio, sturdiness quotient and seedling quality index were also worked out for these twenty-two treatments and result showed that single and combination of biofertilizer treatments influenced the seedling vigour in Indian redwood at 180 DAT (Fig. 1). Seedling Quality Index (SQI) is considered as a promising integrated measure of morphological traits and a good indicator of seedling quality as it computes robustness and biomass distribution of seedlings as compared to individual growth parameters like shoot length, collar diameter (Binotto et al 2010). In the present study, among various biofertilizer treatments, T_{14} (combination of Azospirillum @ 5 ml plant^{-1} + PSB @ 5 ml plant^{-1}) resulted in highest seedling quality index of 0.75 than

Table 1. Influence of biofertilizers on the growth parameters of *S. febrifuga* seedlings at 180 DAT

Treatments	Seedling height (cm)	Collar diameter (mm)	No. of leaves plant^{-1}	Total leaf area plant^{-1} (cm^2)	Root length (cm)	Fresh weight of plant (g)	Dry weight of plant(g)
T_1	11.57	2.83	6.38	241.81	18.28	6.97	1.15
T_2	12.94	4.13	7.51	396.72	18.00	13.77	2.70
T_3	12.87	4.20	6.67	391.87	16.83	12.46	2.30
T_4	13.60	4.15	7.47	354.46	18.44	11.02	2.02
T_5	12.27	3.93	6.40	310.92	17.78	9.73	1.52
T_6	13.47	4.10	7.47	375.43	17.13	13.30	2.48
T_7	12.98	4.20	6.08	369.56	18.06	12.00	1.98
T_8	13.80	3.94	6.67	414.71	20.28	11.63	1.95
T_9	14.66	4.38	5.30	462.37	18.09	16.09	3.21
T_{10}	11.93	4.04	6.13	373.50	17.44	11.35	1.76
T_{11}	13.44	4.11	6.33	361.03	18.28	10.16	1.71
T_{12}	13.07	4.33	5.00	272.11	17.17	6.84	1.25
T_{13}	14.16	4.25	6.40	432.89	16.89	13.20	2.33
T_{14}	16.01	4.90	7.00	469.43	19.28	17.66	3.78
T_{15}	12.55	4.15	4.87	233.88	16.41	8.46	1.56
T_{16}	10.64	3.03	4.83	272.03	15.72	9.69	1.75
T_{17}	13.34	3.73	5.59	343.00	15.61	9.44	2.52
T_{18}	13.44	4.17	6.48	340.00	18.39	12.95	2.20
T_{19}	12.27	3.84	4.55	219.97	17.17	8.05	1.72
T_{20}	12.37	4.03	5.95	326.09	16.56	11.37	1.75
T_{21}	13.08	4.07	6.82	332.55	19.95	11.80	2.13
T_{22}	13.09	3.31	6.53	371.50	14.22	10.56	2.10
Mean	13.07	3.99	6.20	348.45	17.54	11.29	2.07
SEm (±)	0.33	0.09	0.21	11.59	0.22	0.23	0.05
CD (p=0.05)	0.95	0.27	0.61	33.03	0.63	0.65	0.14

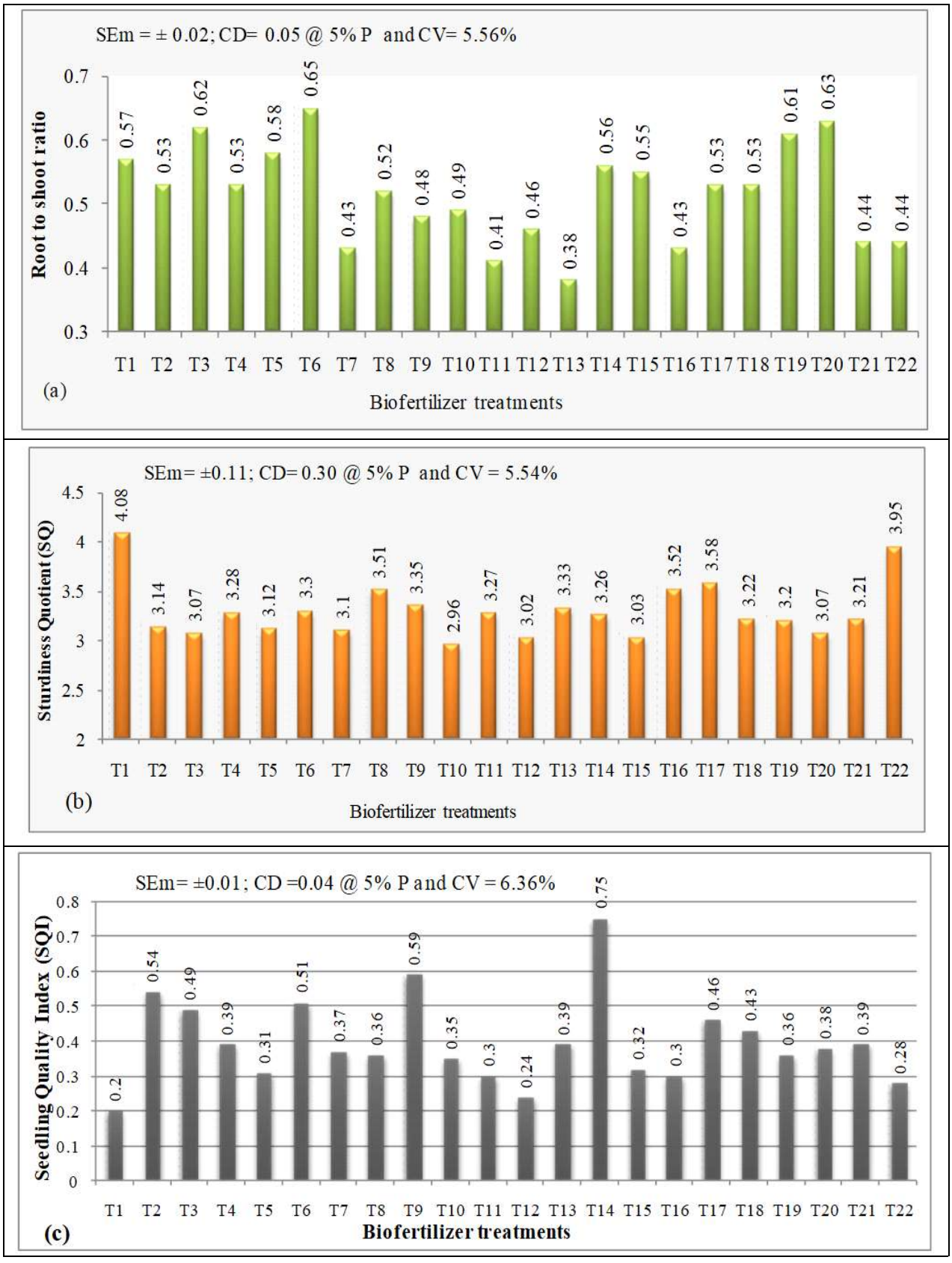

Fig. 1. Influence of biofertilizers on (a) root - shoot ratio; (b) sturdiness quotient(SQ) and (c) Seedling Quality Index (SQI) of *Soymida febrifuga* at 180 DAT

others (Fig. 1). Such synergetic influence of biofertilizer on vigour index was also reported in many forest species like *Santalum album* (Choudhury 2016), *Melia azedarach* (Rajeshkumar et al 2009) and *Azadirachta indica* (Sumana and Bagyaraj 2003). In fact, *Gmelina arborea* seedlings inoculated with AM + PSB + Banana Pseudostem sap resulted in maximum SQI than other treatments including control (Maharana et al 2018). On other hand, the root: shoot ratio is an important measure for seedling survival It relates the water absorbing area of roots to the transpiring area of shoot. A good ratio indicates a healthy plant (Jaenicke 1999). For root: shoot ratio, application of Pseudomonas @ 10 ml plant^{-1} (T_6) resulted in higher ratio of 0.65. It may be due to the fact that nitrogen deficiency in soil media may result in an increased root: shoot ratio (Harris 1992). Such finding was recorded when Pseudomonas inoculated with seedlings of *Swietenia macrophylla* at 90 DAT (Saini 2019) and seedlings of *Anthocephalus cadamba* at 150 DAT (Chauhan 2020).

The lowest sturdiness quotient (2.96), which is a good indicator for sturdiness in the field performance, was achieved by seedlings exposed to combination treatment of Azotobacter @ 5 ml plant^{-1} + PSB 5 ml plant^{-1} (T_{10}), which was followed by other treatments *viz.,* T_{12}, T_{15}, T_3, T_{20}, T_7, T_5, T_2, T_{19}, T_{21}, T_{18} and T_{14}(Fig. 1). Shreedhar and Mohan (2016) reported that the biofertilizer inoculated seedlings showed better sturdiness quotient value as compared to uninoculated seedlings. Maharana et al (2018) reported the lowest SQ of 11.75 in treatment inoculated with Azospirillum + Novel in *Gmelina arborea* seedlings; whereas, Mishra and Channabasappa (2016) recorded lower sturdiness quotient in teak for treatment of VAM + Azospirillum. The study shows that application of biofertilizer not only influence the seedling growth, but also vigour that help the seedlings to perform better in the field.

CONCLUSION

Study shows that there was an influence of biofertilizers in its single and combination treatments on seedling growth and vigour of Indian Redwood. Among several biofertilizer treatments, seedlings of Indian Redwood treated with Azospirillum @ 5ml plant^{-1} + PSB @ 5ml/plant was found to be superior with respect to seedling height, collar diameter, leaf area, fresh and dry biomass of plant along with seedling quality index (SQI). Hence, this combination may be used for raising quality seedlings of Indian Redwood in the nursery for timely transplanting or field planting.

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Effect of Fertilizer Application on Growth, Hebage and Oil Yield in Hybrid Aromatic Tulsi

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Abstract: A field experiment was conducted for an inter-specific hybrid (*Ocimum kilimandscharicum* and *Ocimum basilicum*) variety CIM-Shishir of Ocimum at College of Forestry, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli during 2021-2022 to analyse the response fertilizer application on growth, fresh biomass, oil content and oil yield. Experiment was laid out in randomized block design (RBD) with six treatments (with four replications): T_1(control- no fertilizer), T_2 (FYM 10 T ha^{-1}), T_3 (FYM 10 T ha^{-1}) +100% NPK, T_4 (FYM 10 T ha^{-1}) + 75% NPK, T_5 (FYM 10 T ha^{-1}) +50% NPK, T_6 (RDF @ 160:80:80 NPK. Plant height (110.80 cm), number of primary branches (8.05), fresh biomass yield (537.75 quintal ha^{-1}), oil content in fresh herb (0.70 %) and oil yield (221.25 kg ha^{-1}) was highest in response to FYM (10T ha^{-1}) + 100% NPK application and lowest was in control (no fertilizer application). From these results it was concluded that dose of fertilizer FYM (10T ha^{-1}) + 100% NPK (160:80:80 kg ha^{-1}) increase the growth, fresh biomass yield, oil content and oil yield in hybrid aromatic tulsi.

Keywords: Tulsi, Growth, Fresh biomass, Oil content, Oil yield

Tulsi is an aromatic shrub in the basil family Lamiaceae that is thought to have originated in north central India and now grows native throughout the eastern world tropics. In Ayurveda, tulsi is known as “The Incomparable One,” “Mother Medicine of Nature” and “The Queen of Herbs,” and is revered as an “elixir of life” due to its medicinal and spiritual values. In India, tulsi has been adopted into spiritual rituals and lifestyle practices that provide a vast array of health benefits including anxiety, cough, asthma, diarrhea, fever, dysentery, arthritis, eye diseases, otalgia, indigestion, hiccups, vomiting, gastric, cardiac and genitourinary disorders, back pain, skin diseases, ringworm, insect, snake and scorpion bites and malaria (Cohen 2014). Many species of genus *Ocimum* have been advocated for commercial cultivation under agroforestry land use systems and are found economically viable (Thakur et al 2012, Suvera et al 2015, Kumar et al 2016). Therefore, it is necessary to develop package of practices of cultivation for newly developed varieties (Suvera et al 2016, Rahman et al 2014).

The nutrient management practices involve judicious combination of inorganic fertilizers and organic manures to maintain soil fertility and to improve the production potential of any crop (Thakur et al 2009; Verma et al 2010; Khalid et al 2015;). This approach is reasonably cheap, technically sound and practically feasible and is capable of maintaining the sustainability in production. Keeping this view, the experiment was carried out to study the “effect of fertilizer application on growth, biomass oil content and oil yield in hybrid aromatic tulsi crop” was carried out.

MATERIAL AND METHODS

A field experiment was conducted for an inter-specific hybrid (*Ocimum kilimandscharicum* and *Ocimum basilicum*) variety CIM-Shishir of *Ocimum* at College of Forestry, Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli during 2021-2022. It is Konkan region of Maharashtra situated at an elevation of 243.84 m above sea mean sea level and located at 12° 58' North latitude, 77° 55' East longitude. The climate of the Dapoli is warm humid with an annual rainfall 3000 to 3500 mm. The climate is typically tropical with hot and humid summers having heavy rainfall during monsoon and warm winters. The experiment area is comprised of red sandy loam soil with uniform fertility with available nitrogen, phosphorus and potassium of 288.51, 7.8 and 202.94 kg/ha, respectively. Soil has pH, EC and organic carbon values 5.16, 0.17 dsm^{-1} and 1.51%, respectively. The experiment was laid out in randomized block design (RBD) with four replications with six treatments *viz*., T_1(control- no fertilizer), T_2 (FYM 10 T ha^{-1}), T_3 (FYM 10 T ha^{-1}) +100%NPK, T_4 (FYM 10 T ha^{-1}) + 75% NPK, T_5(FYM 10 T ha^{-1}) +50% NPK, T_6 (RDF @ 160:80:80 NPK). Field was prepared following standard practices and divided into plots of 3 m x 4.2 m size. As per treatment dose, FYM was applied to each plot and incorporated well in the soil 10 days prior to plating and chemical fertilizers were applied as per package of practice at the time of seedling planting. After each harvest (90 days interval), remaining fertilizer dose was applied. Seedlings were raised through cutting in nursery. One-month-old seedling were transplanted in plots of 3 x 4.2 m size at 60 x 60 cm spacing in November, 2021 and light

irrigation was given immediately after planting. Weeding was done at periodic intervals to keep the field weed free. Subsequent irrigations were given as per the crop requirement based on soil moisture content. First harvest was taken (at 50% full bloom stage) at 90 days after planting and subsequent cuttings were again taken at 90 days intervals. Five plants from each plot were used to record the average height of the plant, number of primary branches, after each harvest fresh weight of fresh biomass was recorded and then the plants were used for the oil extraction with help of Clevenger apparatus and oil content is recorded.

RESULTS AND DISCUSSION

Growth performance: Significant differences were observed in the plant height up to the harvest period of the hybrid aromatic tulsi (Table 1) in response to different integrated nutrient management practices.

Maximum plant height (110.00 cm) and number of primary branch/plant (8.00) was observed in response to T_3 (FYM 10 T ha^{-1}) +100% NPK application and lowest (75.50 cm) was in control T_1. On the basis of results the effect of treatments on plant height was in the order $T_3>T_6>T_4>T_5>T_2>T_1$.

The results are in close conformity with the finding of Naggar et al (2015) and Rajit et al (2019). This might be due to sufficient supply to nitrogen to crop. It might be due to higher nitrogen content in farm yard manure and NPK fertilizers been used in T_4 and T_5. T_4 and T_6 treatment are statistically similar.

Fresh biomass yield: It is evident from the (Table 1) that the application of FYM 10 T ha^{-1} +100% NPK resulted in significantly highest fresh herbage yield of 537.75 q ha^{-1} (Three ratoon crop). The lowest fresh biomass yield (205.50 q ha^{-1}) was obtained in T_1 (control- no fertilizer). Combined application of organic manure along with inorganic fertilizer regulate the supply of nutrients which in turn increase the crop yield (Merestala 1996; Thakur et al 2009). Similar findings were also reported by Mohamad et al (2014) in *Ocimum basilicum* and Verma et al (2010) in *O. sanctum*.

Essential oil content and oil yield: Application of different levels of FYM and inorganic fertilizer showed a significant effect on essential oil content (Fig. 1) and yield of hybrid aromatic tulsi (Table 1). Application of FYM 10 T ha^{-1} +100% NPK gave maximum essential oil content (0.70%) whereas the lowest (0.31 %) was from control- no fertilizer. Soil nutrient get enhanced with application of organic manure resulting in positive effect on the growth, herbage and oil yield (Khalid et al 2015, Thakur et al 2009).

Oil production is the most important parameter in aromatic hybrid tulsi farming. Different levels of FYM and inorganic fertilizer showed a significant increase in oil production which can be attributed to the increased NPK doses either through organic or inorganic form (Table 1). In the present study, oil yield per hectare increased with the increase of FYM doses, and application FYM 10 T ha^{-1} +

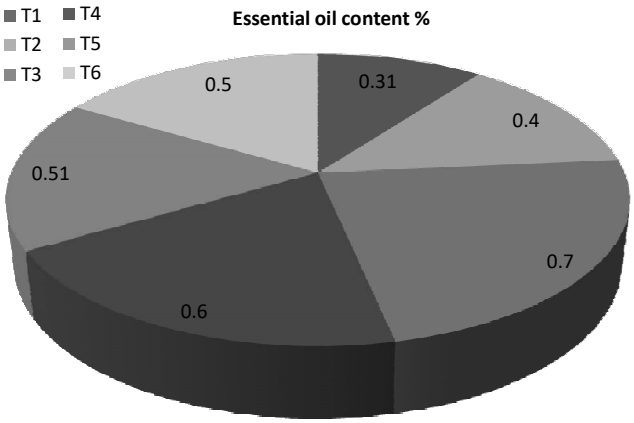

Fig. 1. Essential oil content in aromatic tulsi crop

Table 1. Effect of fertilizer application on growth and yield parameter in hybrid aromatic tulsi crop

Treatment	Plant height (cm)	No. of primary branches	Fresh biomass (q ha^{-1})	Essential oil content %	Oil yield (kg ha^{-1})
T_1 (control- no fertilizer)	75.50	3.25	205.50	0.31	151.0
T_2 (FYM 10 T ha^{-1})	83.50	4.75	299.75	0.40	167.0
T_3 (FYM 10 T ha^{-1}) +100%NPK	110.80	8.05	537.75	0.70	221.0
T_4 (FYM 10 T ha^{-1}) + 75% NPK	97.00	6.02	465.50	0.60	191.2
T_5 (FYM 10 T ha^{-1}) +50% NPK	84.00	5.02	424.25	0.51	177.5
T_6 (RDF @ 160:80:80 Kg NPK	97.75	4.77	421.50	0.50	173.2
SE	1.01	0.157	4.26	0.005	2.20
CD (p=0.05)	3.04	0.474	12.85	0.016	6.63
CV %	2.21	5.93	2.17	2.15	2.44

100% NPK gave maximum oil yield in the tulsi crop (221 kg ha^{-1}) and the lowest oil yield (151.0 kg ha^{-1}) was obtained in T_1 (control- no fertilizer). Integrated nutrient management improve the chemical, physical and biological soil proprieties that reflect positively on plant growth and oil yield (Patra et al 2000, Thakur et al 2014). These results are similar to the observation of Dadkhah (2012). The outcome of the present investigation revealed that the maximum fresh herbage yield, essential oil content, oil yield was obtained with combined application of FYM 10 T ha^{-1} +100% NPK.

CONCLUSION

The study indicated that application of FYM 10 T ha^{-1} + 100% 160: 80:80 kg ha^{-1} NPK recommended organic and inorganic fertilizer as basal and the remaining fifty per cent as top dressing after each harvest (90 days interval) proved best for aromatic tulsi crop to achieve better growth, higher fresh herbage and oil yield.

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Distribution and Mapping of *Ficus neriifolia* Smith: A Multipurpose Agroforestry Tree in Chamoli District, Uttarakhand, India

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Abstract**:** *Ficus neriifolia* locally called as *Dudhla, Thilook, Dudhoi* is one of the most important leaf fodder species in North- Western Himalaya, India during lean period. Keeping the importance of the species, the present study was conducted on distribution and mapping of *Ficus neriifolia* in Chamoli district in North –Western Himalaya, India. Based on the field survey we identified 33 sites/villages in eight development blocks at different altitudes in Chamoli district. The potential distribution sites occurred in the district from 1100-2200 m asl. In all 33 sites/villages, GPS locations were noted and distribution map was prepared with the help of GIS software. Every selected village/site in each block, natural habitat/occurrence of the species was identified at each altitude. During the survey, maximum (07) potential sites/villages were identified in Dewal block followed by 05 sites/villages in Tharali block and minimum (02) potential sites/villages were indentified in Dasholi block. As far as the altitudinal variations is concerned, the occurrence of the species at highest elevation (2205 m) in Kandai village (Dewal) and at lowest elevation (1042 m) in Kaleshwar village (Karnaparyag). In each site, population density of the species was also recorded. Maximum tree density (11.0 tree/200 m^2) was recorded at Talwari site/village and minimum (2.0 tree/200 m^2) at Senti site/village.

Keywords**:** *Ficus neriifolia,* Chamoli district, Altitudinal, Sites/Villages, Density, *Grewia oppositifolia*

Genus *Ficus*, commonly known as Figs are considered as a keystone species in sub-tropical and tropical rain forests as it plays a very fundamental role in the ecosystem, due to its fruits which are eaten by insects, birds and animals throughout the year. The genus *Ficus* is an exceptionally large pan tropical genus with over 700 species (Berg 1989) and belongs to the family Moraceae. The genus is distributed throughout the world primarily in subtropical and tropical regions (Corner 1965, Berg 1989, Berg and Corner 2005). Many species of Ficus are very common in different biogeographic regions. Although, the great majority of the species grow in lowlands but some of them reach up to about 2,000 m altitudes (Chaudhary et al 2012, Gaur 1999). Only about 10 species chiefly occurring in the North Western Himalaya extend their distribution towards Westward of Pakistan (Chaudhary et al 2012).

It is distributed in India (Arunachal Pradesh, Assam, Meghalaya, Mizoram, Nagaland, Uttarakhand, and Western to Eastern Himalayas from 500 - 2200 m. *F. neriifolia* often planted near villages for cattle fodder in Bhutan, China, Indochina, Myanmar, Nepal (Corner 1965). *Ficus* species are the most interesting group of trees in Nepal, not only of their useful value but also of their growth habits and religious significance. It is retained as a single, large genus because it is well defined by its unique reproductive system, involving Syconia fig- and specialized pollinator wasps (Novotny et al 2002). *F. neriifolia* (Dudhla/Thilook/Dudhoi) is the common tree species which are being cultivated in and around farmlands and they provide a source of leaves fodder during the dry season and very high animal feed in Nepal (Panday 1982).

Agriculture with animal husbandry is the main profession of rural people of this Himalayan region. Livestock plays an important role in the economy of Uttarakhand as it is the important source of income of rural people. There is a vast diversity of fodder plants. Demand for fodder is uniform throughout the year although unavailability of green forage during winter has always remained a serious issue resulting in nutritional deficiency in mulching animals. Thus, there is a need to explore fodder plants in Uttarakhand Himalayas. Keeping in views this genus is one of the most important leaf fodder species in North–Western Himalaya India during fodder scarcity period has been selected for the present study. There was no information regarding distribution of *F. neriifolia* species in the Chamoli district.

MATERIAL AND METHODS

The present study was conducted in Chamoli district in the North-Western part of Uttarakhand. Geographically the district is located between 29° 55′00″ to 31°03′45″ N Latitude and 79°02′39″ to 80°03′29″ E Longitude and altitudinal varies from 800-8000 above sea level. The climate in the study area can be divided into three distinct seasons, cool and relatively dry winter

(November to March), warm and dry summer (mid-April to June) and rainy (July to mid-September). District Chamoli has six tehsils, viz., Joshimath, Chamoli, Karnaprayag, Pokhari, Gairsain and Tharali. It is divided into nine development blocks which are Joshimath, Dasoli, Pokhari, Ghat, Karnaprayag, Tharali, Narayanbagar, Dewal and Gairsain.

A reconnaissance field survey was carried out to collect information of the species in the district during 2020 to 2021. Stratified random sampling was used for detailed surveys in each site. In the first stage, out of nine developmental blocks, the species occurrence in eight blocks out of nine development blocks (Dasoli, Pokhari, Ghat, Karnaprayag, Tharali, Narayanbagar, Dewal and Gairsain) representing altitudinal variation i.e. (1100-2200 m) were selected in the district. Seven villages/sites from Dewal, five villages from Tharali, four villages from Ghat, Pokhari, Karanprayag & Gairsain each, three villages from Narayanbagar, two villages from Dasholi block considering the altitudinal variation. In the second stage of sampling, a detailed questionnaire based survey in each selected village was conducted. Thus, a total thirty three villages/sites were selected randomly from eight developmental blocks in the district. Every selected village/site in each block, natural habitat/occurrence of the species has been identified at each altitude. In each site five and six sample plots were laid out for estimation of tree density. The size of plot was 200 m^2.

Semi structured open ended questionnaire survey was conducted during the field visit. During the survey, various questions related to importance, how to use, time and season to use, about fodder quality *etc*. of this species were asked to the villagers. Attempts were made to collect all possible information regarding GPS points at each site, the traditional use of the plants, mode of usage and part (s) used. Information regarding locality, seasonal availability, and mode of use was also recorded by interviewing the villagers, elderly people, and shepherds of these villages. The specimens were collected and identified with the help of herbarium from Botany department at HNB Garhwal (Central) University and through previous works (Duthie 1906, Gaur 1999).

Identification of the natural growing sites of *Ficus neriifolia* across the Chamoli Garhwal district was conducted in different places. Based on reconnaissance field surveys potential natural habitat sites were identified in the district. Habitat mapping of *Ficus neriifolia* across the Chamoli region was conducted. During the field survey, the GPS point to take the reference point of habitat location of *Ficus neriifolia* in different areas in the district was noted. Wherever the species occurred GPS locations were noted. After taking of GPS location from different areas georeferencing and mapping was conducted in the Department GIS laboratory through the using of QGIS 3.14 GIS software (SOI 2022). With the help of GPS locations and using GIS software of QGIS 3.14, distribution map of *Ficus neriifolia* was prepared of the Chamoli district.

RESULTS AND DISCUSSIONS

Based on the available literature from India Gaur (1999) and from Nepal Kunwar and Bussmen (2006) the following characteristics were noticed of the *Ficus neriifolia* species in Table 1.

We surveyed all the 9 blocks in Chamoli District and the species occurrence was observed in 8 blocks. Out 8 blocks the species found in total 33 villages (Table 2). With the help of GPS point and QGIS Software distribution map was prepared and all the 33 surveyed villages/site were plotted in

Table 1. Characteristics and uses of *Ficus neriifolia*

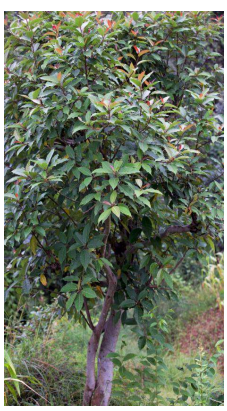
Species name	Characteristics	fodder plant species	Uses
Ficus neriifolia 	*Ficus* grows as a tree up to 15 m (50 ft) tall with smooth, dark grey bark on its trunk. The hairless, leathery oval to lanceolate (spear-shaped) leaves is up to 8–18 cm long by 3–6.5 cm wide, and often asymmetrical in shape. The 8–10 cm diameter figs are rounded, oval, or cylindrical and grow in pairs off older branches	The foliage of *Ficus neriifolia* is used as fodder and its wood used as fuel in North-Western Himalaya	The juice of the stem bark is used as a folk remedy for conjunctivitis and boils. This fig tree is considered good for indoor bonsai in temperate climates, and it is easily shaped and pruned.  

Table 2. Distribution, density and associated species of *Ficus neriifolia* in Chamoli district

Block name	Village name	Mode of use	Density (trees/200 m^2)	Associated tree species	Latitude	Longitude
Gairsain	Mehalchari	Leaves used as fodder	6	*Celtis australis, Morus alba, Acer* spp., *Grewia oppositifolia, Quercus glauca, Citrus sinensis*	29°59'03"	79°19'17"
	Dhargar	Leaves used as fodder	5	*Ficus palmata, Celtis australis, Grewia oppositifolia, Melia azedarach, Bauhinia purpurea, Citrus sinensis*	29°59'44"	79°19'01"
	Panchali	Leaves used as fodder	6	*Bombax cebia, Aesculus indica, Bauhinia variegata, Bamboo* spp.	30°01'22"	79°17'42"
	Ganwali	Leaves used as fodder	4	*Melia azedarach ,Toona serrata, Acacia catechu, Citrus sinensis*	30°02'51"	79°17'19"
Karanparyag	Kaleshwar	Leaves used as fodder	4	*Acacia catechu, Melia azedarach, Grewia oppositifolia*	30°17'00"	79°14'53"
	Langasu	Leaves used as fodder	3	*Ficus palmeta, F. sarmentosa, Grewia oppositifolia, Celtis australis*	30°17'21	79°17'18
	Biroli	Leaves used as fodder	4	*Acacia catechu, Bombax cebia, Celtis australis, Grewia oppositifolia*	30°17'35"	79°18'09"
	Sonla	Leaves used as fodder	5	*Grewia oppositifolia, Quercus leuchotrichophora, Ficus palmata, Alnus nepalensis*	30°19'02"	79°18'27
Ghat	Sarpani	Leaves used as fodder	3	*Grewia oppositifolia, Morus alba, Celtis australis,*	30°14'26"	79°27'27"
	phali	Leaves used as fodder	4	*Ficus auriculata, Quercus leuchotrichophora, Melia azedarach, Cinnamomum tamala*	30°14'32"	79°26'41"
	Senti	Leaves used as fodder	2	*Pinus roxburghii, Melia azedarach, Alnus nepalensis,*	30°14'12"	79°26'55"
	Narangi	Leaves used as fodder	*4*	*Ficus palmeta, Grewia oppositifolia, Quercus leuchotrichophora*	30°15'50"	79°27'52"
Pokhari	Pokhari	Leaves used as fodder	3	*Prunus cersoides, Quercus leuchotrichophora, Rhododendron arboreum, Citrus sinensis*	30°20'40"	79°11'43"
	Devsthan	Leaves used as fodder	4	*Alnus nepelensis, Toona serrata, Pyrus pashia, Ficus palmeta, Citrus sinensis*	30°20'22"	79°12'07"
	Vishal	Leaves used as fodder	8	*Ficus palmata, Prunus cersoides, Quercus leucotrichophora, Grewia oppositifolia, Bombex cebia, Citrus sinensis*	30°20'39"	79°12'34"
	Devartalla	Leaves used as fodder	4	*Ficus auriculata, Grewia oppositifolia, Bombex cebia, Bauhinia purpurea, Citrus sinensis*	30°20'02"	79°12'39"
Dasholi	Gair	Leaves used as fodder	7	*Prunus cersoides, Grewia oppositifolia, Celtis australis, Quercus leucotrichophora, Citrus sinensis*	30°24'57.2"	79°18'29"
	Mandal	Leaves used as fodder	5	*Grewia oppositifolia, Celtis australis, Ficus auriculata, Ficus palmata, Citrus sinensis*	30°27'48"	79°16'08"
Narainbagar	panti	Leaves used as fodder	5	*Myrica esculenta, Pinus roxburghii, Alnus nepalensis, Aesculus indica*	30°07'33"	79°23'18"
	Bedula	Leaves used as fodder	6	*Ficus palmata, Grewia oppositifolia, Ficus auriculata*	30°08'15"	79°22'29"
	Paithani	Leaves used as fodder	7	*Prunus cersoides, Ficus palmata, Grewia oppositifolia, Toona serrata.*	30°07'16"	79°25'21"
Tharali	Gwaldam	Leaves used as fodder	8	*Quercus wallichiana, Ficus auriculata, Grewia oppositifolia, Bombex cebia, Bauhinia purpurea, Citrus sinensis*	30°01'28"	79°34'34"
	Loda	Leaves used as fodder	9	*Ficus palmata, Grewia oppositifolia, Pinus roxburghii, Citrus sinensis*	30°00'27"	79°31'24"
	Talwari	Leaves used as fodder	11	*Prunus pashia, Myrica esculenta, Citrus sinensis*	30°02'01"	79°31'54"
	Lolti	Leaves used as fodder	7	*Ficus palmata, Bahunia purpurea, Prunus pashia, Quercus leuchotrichophora, Citrus sinensis*	30°02'42"	79°30'00"
	Kulsari	Leaves used as fodder	9	*Malus domestica, Toona serrata, Celtis australis, Quercus leuchotrichophora.*	30°05'09"	79°27'28"
Dewal	Dewal	Leaves used as fodder, Bark latex is applied on swelling and joint pains	6	*Alnus nepalensis, Ficus palmata, Myrica esculenta, Pinus roxburghii, Malus domestica, Pyrus pashia, Aesculus indica, Quercus glauca, Citrus sinensis*	30°02'52"	79°35'27"

Cont...

Table 2. Distribution, density and associated species of *Ficus neriifolia* in Chamoli district

Block name	Village name	Mode of use	Density (trees/200 m)	Associated tree species	Latitude	Longitude
	Purna	Leaves used as fodder	8	*Prunus pashia,Alnus nepalensis, Toona serrata, Grewia oppositifolia, Bombex cebia, Citrus sinensis, Malus domestica*	30°03'09"	79°34'48"
	Kandai	Leaves used as fodder	6	*Celtis australis, Morus alba, Grewia oppositifolia, Myrica esculenta.*	30°04'08"	79°37'09"
	Talor	Leaves used as fodder	7	*Myrica esculenta, Pinus roxburghii, Alnus nepalensis, Aesculus indica*	30°02'12"	79°36'00"
	Deosari	Leaves used as fodder	8	*Morus alba, Quercus leuchotrichophora, Ficus auriculata,Rhododendron arboreum, Myrica esculenta*	30°02'07"	79°35'42"
	Kail	Leaves used as fodder	5	*Pines roxburghii,Toona serrata, Grewia oppositifolia,Celtis australis, Quercus glauca, Citrus sinensis*	30°03'22"	79°35'50"
	Sawad	Leaves used as fodder	8	*Rhododendron, Grewia oppositifolia, Pinus roxburghii, Quercus leuchotrichophora, Citrus sinensis*	30°04'11"	79°36'54"

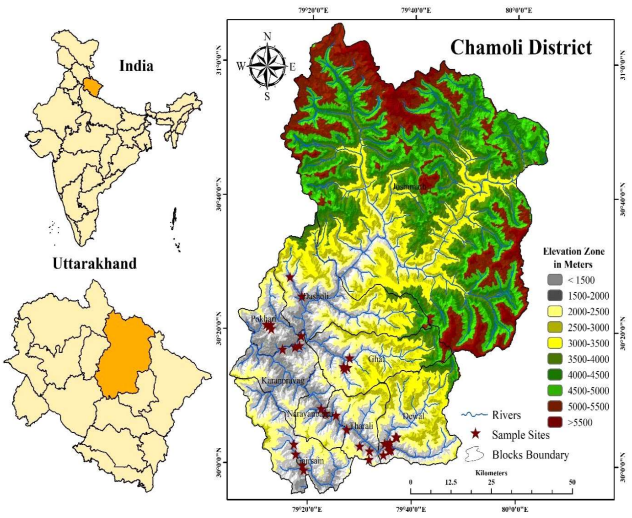


Fig. 1. Identified potential sites/villages locations of *Ficus neriifolia* in Chamoli district

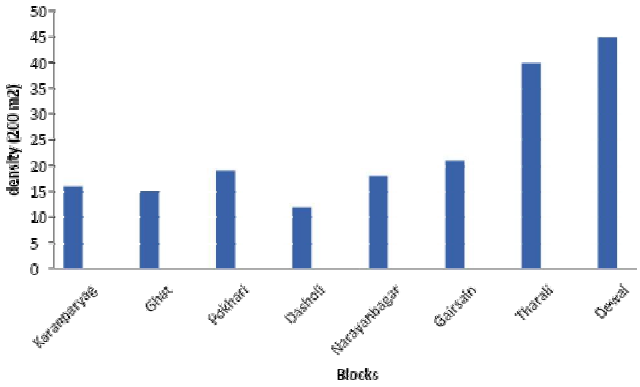


Fig. 2. Tree density of *Ficus neriifolia* at different blocks in Chamoli district

the map (Fig. 1). The locations of the species in the surveyed site were highlighted as red stars in the map.

During the survey, maximum (07) potential sites/villages were identified in Dewal block followed by 05 sites/villages in Tharali block and minimum (02) potential sites/villages were identified in Dasholi block (Table 2). As far as the altitudinal variations is concerned, the occurrence of the species at highest elevation (2205 m) in Kandai village (Dewal) and at lowest elevation (1042m) in Kaleshwar village (Karnaparyag). The geographical locations of these sites are 30°04'08" N Latitude and 79°37'09" E Longitude and 30°17'00" N Latitude and 79°14'53" E Longitude respectively at Kandai and Kaleshwar village. The associated species are *Celtis australis, Morus alba, Acer spp., Grewia oppositifolia, Pinus roxburghii, Myrica esculenta, Desmodium laxiflorum, Prunus cersiodes and Prunus persia* found in these sites/villages (Table 2).

As for as tree population of *Ficus neriifolia is* concerned, maximum density (45 tree/200 m^2) population was recorded, at Dewal block followed by (44 tree/200 m^2) at Tharali block, while minimum density (12 tree/200 m^2) at Dasholi block (Fig. 2). The associated species are *Grewia oppositifolia, Toona serrata, Alnus nepalensis, Ficus auriculata, Myrica esculenta, Malus domestica, Citrus sinensis, Prunus pashia, Aesculus indica, Bombax cebia, Quercus glauca, Quercus leuchotrichophora and Prunus cersoides* in these sites.

Ficus neriifolia tree density in each surveyed site was concerned, maximum tree density (11.0 tree/200 m^2) was recorded at Talwari site/village followed by (9.0 tree/200 m^2) at Kulsari and Loda site/village in Tharali block respectively. Whereas, minimum (2.0 tree/200 m^2) tree density was recorded at Senti site/village (Ghat block), followed by (3.0 tree/200 m^2) at Langasu site/village (Karnparyag block), Sarpani site/village (Ghat block) and Pokhari site/village (Pokhari block) respectively (Table 1). The higher density in Talwari site may be due to higher altitude and low temperature for suitable habitat conditions for its growth and

development. While lower density may occur in these sites due to lower altitude and high temperature. The associated species in these sites/villages are *Grewia oppositifolia, Toona serrata, Alnus nepalensis, Ficus auriculata, F.palmata, F. Sarmentosa, Myrica esculenta, Malus domestica, Citrus sinensis, Prunus pashia, Aesculus indica, Bombax cebia, Quercus glauca, Quercus leuchotrichophora, Melia azedarach, Cinnamomum tamala* and *Morus alba.*

*Ficus neriifolia*is considered very good for leaf fodder. Good quality fodder is characterised by high dry matter, good level of crude protein, high palatability, high digestibility, low lignin content, adequate carotene and vitamin levels, high mineral content, low levels or lack of anti-nutritional substances for animal growth and performance (Kaithwas et al 2020). The villagers use *Ficus neriifolia* leaves as good fodder because the thickness of cow's milk is also in good quantity.

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Effects of Soil Types on the Growth and Development of *Amaranthus* var. Durga (IC35407) (Ramdana)

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Abstract**:** The study examined the impact of soil types on *Amaranthus* var. Durga (IC35407) germination and growth in a laboratory experiment across seven soil types: barren land, cultivated land, pine, quercus, deodar, mixed forest, and populus. The fastest germination occurred on the first day was in populus soil, while no significant differences were found on days 2, 3, and 4. Mean daily germination, seedling lengths, and fresh and dry weights were highest in mixed Forest and populus soil, while lowest in deodar soil. Shoot length was greatest in quercus and mixed forest soil, while the longest root length was observed in mixed forest soil. Cultivated land soil had the highest seed vigor index-I and index-II, while mixed forest and populus soil had the lowest values. Deodar soil had the highest mortality rate, while mixed forest soil had the lowest. These findings provide valuable insights into the cultivation and management practices of *Amaranthus* var. Durga, enhancing the understanding of the crop's growth and cultivation practices.

Keywords**:** Germination, Soil types, Plant growth, Variability, Vigour Index

Amaranthus var. Durga (IC35407), commonly known as Ramdana, is a highly nutritious and versatile plant that belongs to the Amaranthaceae family. It is an annual herbaceous crop that has gained significant attention in recent years due to its potential as a sustainable food source and its adaptability to different environmental conditions (Das 2016, Kavinila et al 2020). Ramdana is known for its high protein content, essential amino acids, vitamins, and minerals, making it an important crop for addressing nutritional deficiencies and food security challenges (Ruth et al 2021, Alegbejo 2013). The growth and development of any plant species are influenced by various factors, and soil type plays a crucial role in determining the success and productivity of crops (Fageria et al 2008, Tanzin 2018). Soil type refers to the physical and chemical properties of the soil, including texture, structure, fertility, and nutrient composition. Different soil types have distinct characteristics that directly impact plant growth, nutrient availability, water-holding capacity, and root development (Begum 2003, Esmaeilzadeh and Ahangar 2014).

Understanding the effects of soil types on the growth and development of *Amaranthus* var. Durga is vital for optimizing cultivation practices, improving yield, and enhancing overall crop performance. By examining the influence of various soil types on Ramdana, farmers, and researchers can identify the most suitable soil conditions for maximizing production and implementing sustainable agricultural practices (Singh 2009, Zhong et al.2020). The composition and structure of the soil affects plant growth in several ways. The texture of the soil determines its water-holding capacity and drainage characteristics. Sandy soils, for instance, tend to have large particles and drain water rapidly, which can lead to poor water retention and lower nutrient availability for the plants (Bhadha et al 2017). Conversely, clay soils, composed of fine particles, have higher water-holding capacity but may suffer from poor drainage and aeration, potentially causing root rot or other adverse effects on plant growth. Soil fertility is another critical factor influencing plant growth. Fertile soils contain an adequate supply of essential nutrients required for plant development (Jones 2012, Ohshiro et al 2016, Kumar 2018). Nitrogen, phosphorus, and potassium are primary macronutrients that plants require in relatively large quantities. Additionally, micronutrients like iron, zinc, and manganese are crucial for various physiological processes (Maathuis 2009). The availability of these nutrients in the soil greatly affects the growth, yield, and nutritional quality of *Amaranthus* var. Durga.

Furthermore, the pH level of the soil affects the availability of nutrients to the plant. Each plant species has an optimal pH range for growth, and deviations from this range can negatively impact nutrient uptake and utilization. *Amaranthus* var. Durga generally thrives in slightly acidic to

neutral soils with pH levels ranging from 6.0 to 7.5. Acidic or alkaline soils can hinder nutrient availability, disrupt root development, and ultimately limit the growth potential of Ramdana. Soil structure, including its aggregation and porosity, influences root penetration, oxygen availability, and the movement of water through the soil profile. Well-structured soils with good aggregation allow roots to penetrate easily, facilitating nutrient and water uptake. The compacted or poorly structured soils can impede root growth, limiting access to nutrients and leading to stunted plant development. The objective of this study is to examine the effects of different soil types on the germination and growth of *Amaranthus* var. Durga (IC35407) (Ramdana).

MATERIAL AND METHODS

Study area: The study was conducted from January to July at University of Horticulture and Forestry, Ranicahuri campus, located in Tehri Garhwal, Uttarakhand. The experimental site is situated approximately 10 km away from Chambaat, at an altitude of about 2100 m above mean sea level. The study area falls within the mid-hill zone of Uttarakhand, positioned between 30°17' N latitude and 78°30' East longitude. During the study period, various abiotic factors influenced the growth and development of *Amaranthus* var. Durga (IC35407) (Ramdana). Temperature played a crucial role, with average temperatures ranging from 7.5°C to 22.5°C [lowest in January and Highest in June]. Precipitation patterns also affected the plants, with an average rainfall of average rainfall during the study period is approximately 76.33 (mm) whereas, with the highest rainfall in the month of July] during the experimental period. Additionally, factors such as sunlight intensity, humidity levels, and soil moisture content contributed to the overall environmental conditions experienced by the plants. These abiotic factors collectively shaped the growth, germination, and physiological responses of *Amaranthus* var. Durga (IC35407) (Ramdana) throughout the study.

Soil collection: In February to March 2021, soil samples were collected from the temperate region. Seven different soils, namely pine soil, deodar soil, cultivated soil, quercus soil, populus soil, barren land soil, and mixed forest soil, were obtained from a depth of 15 to 30 cm below the soil surface. A "V-shaped" cut was made using a spade or similar tool to reach the desired depth at each sampling spot. At least 4-5 samples were collected from each designated sample unit and placed on a newspaper. The collected samples were then thoroughly mixed to ensure homogeneity, and any foreign materials such as roots, stones, pebbles, and gravel were removed. The bulk volume of the samples was reduced using the quartering method. This involved dividing the thoroughly mixed sample into four equal parts, discarding two opposite quarters, and re-mixing the remaining two quarters. This process was repeated until the desired sample size was obtained. The collected soil samples were carefully placed in poly bags for further analysis.

Germination and growth: For the germination experiment, 10 seeds of *Amaranthus* were sown in each Petri plate, with three replications. The soil from each sample was evenly distributed in the Petri dishes, ensuring consistent seed placement. For the speed germination analysis, the number of seedlings emerging from the seeds in the petri dish was counted daily from the day of planting until germination was complete. The germination percentage was calculated using the formula: GP = (seeds germinated/total seeds) x 100. The germination rate was determined by calculating GP at different time intervals after planting and plotting the data. Mean daily germination was calculated by dividing the final germination by the number of days from sowing to the end of the test period. The speed of germination was determined by identifying the peak value, which represents the maximum mean germination reached during the test period. The seedling length was measured by randomly selecting five seedlings from each replication and recording their lengths in centimeters. The average length of these seedlings was calculated. The seedling's fresh weight was determined by selecting five seedlings, the same ones used for measuring the seedling length and recording their fresh weights in milligrams. For seedling dry weight measurement, the selected seedlings were dried in a hot air oven at 60°C for 24 hours, cooled in desiccators, and then weighed on an electronic balance. The average weight of dried seedlings from each replication was calculated as the dry weight of the seedlings in milligrams. Moisture percentage was calculated using the formula: Moisture percentage = (fresh weight of the seedling – dry weight of seedling) / fresh weight of the seedling × 100. The seed vigor index was assessed by multiplying the standard germination percentage by the average seedling length for Seed Vigor Index I, and by multiplying the standard germination percentage by the average seedling dry weight for Seed Vigor Index II. The mortality rate was determined by subtracting the initial germination from the final germination and dividing it by the initial germination.

Statistical analysis: The statistical analysis of the data was performed using STPR-3 Software. This software package offers a comprehensive range of statistical tools and techniques to analyze and interpret experimental results. The collected data on various parameters such as speed germination, germination percentage, mean daily germination, seedling length, seedling fresh weight, seedling

dry weight, moisture percentage, seed vigor index, and mortality rate were input into the STPR-3 Software for further analysis.

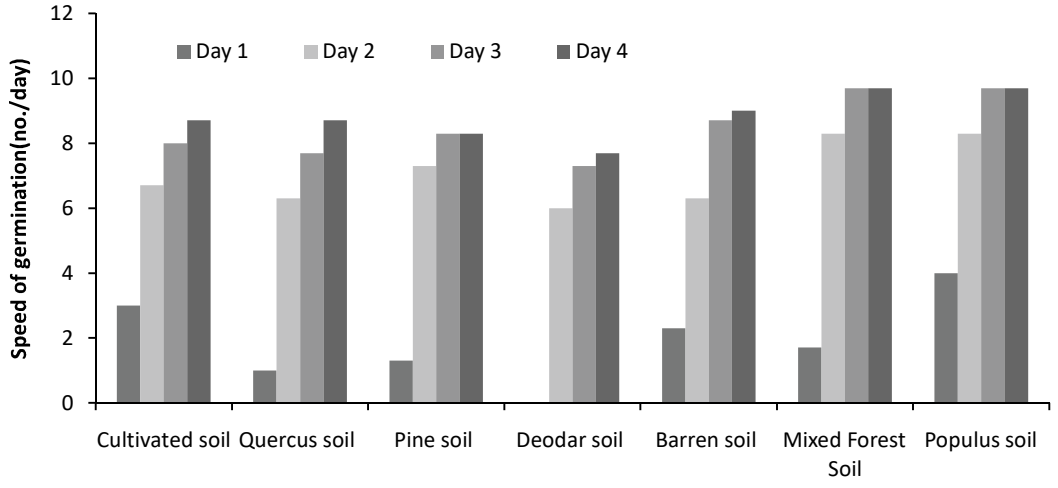
RESULTS AND DISCUSSION

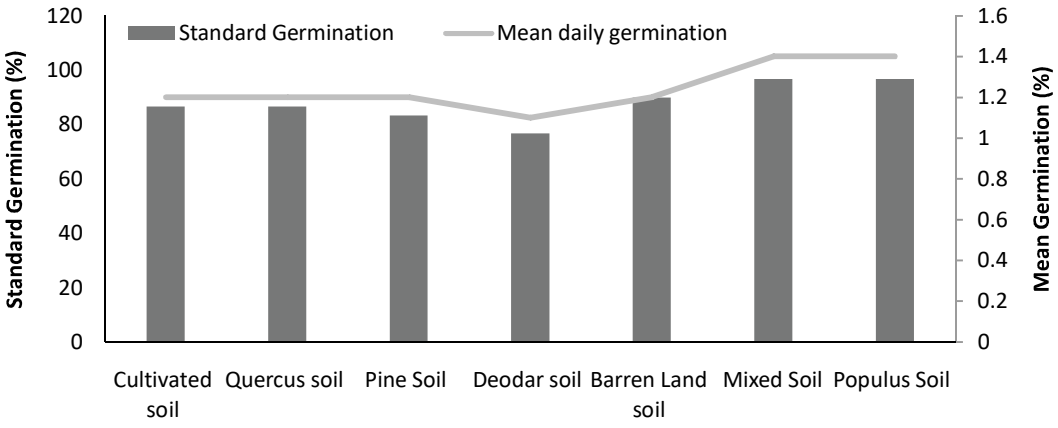
Speed of germination: There were significant differences among the different treatments on the first day, with the highest speed of germination observed in populus soil, which was comparable to barren land soil. From the second to the fourth day, there were no significant differences among the treatments, and the highest speed of germination was observed in mixed forest soil and populus soil, while the lowest was in deodar soil. There was a highly significant interaction between seed depth and soil type, and plant growth was higher in the lighter soils.

Mean daily germination and standard germination: The standard germination of Amaranth showed no significant difference among the treatments, with the highest germination observed in mixed forest soil and populus soil, and the lowest in deodar soil. The mean daily germination also showed no significant difference among the treatments, with the highest mean daily germination observed in mixed forest soil and populus soil, and the lowest in deodar soil (T_4). Kavinila et al (2020) also reported maximum germination of 83% and a minimum of 72% in *Amaranthus*.

Shoot, root, and seedling length: Shoot length showed a significant difference among the treatments, with the highest shoot length observed in quercus soil and mixed forest soil, which was comparable to pine soil. Root length showed no significant difference among the treatments, but the highest root length was observed in mixed forest soil, while the lowest was in barren land soil and cultivated soil. Seedling length showed a significant difference among the treatments, with the highest seedling length observed in mixed forest soil, which was comparable to deodar soil, and the lowest in cultivated soil. Similar results were reported by Kavinila et al. (2020) in *Amaranthus.*

Seed vigour index-I, seed vigour index-II, moisture content, mortality rate, fresh and dry weight: Fresh weight and dry weight showed a significant difference among the treatments, with the highest values observed in populus soil and mixed forest soil, and the lowest in cultivated soil.





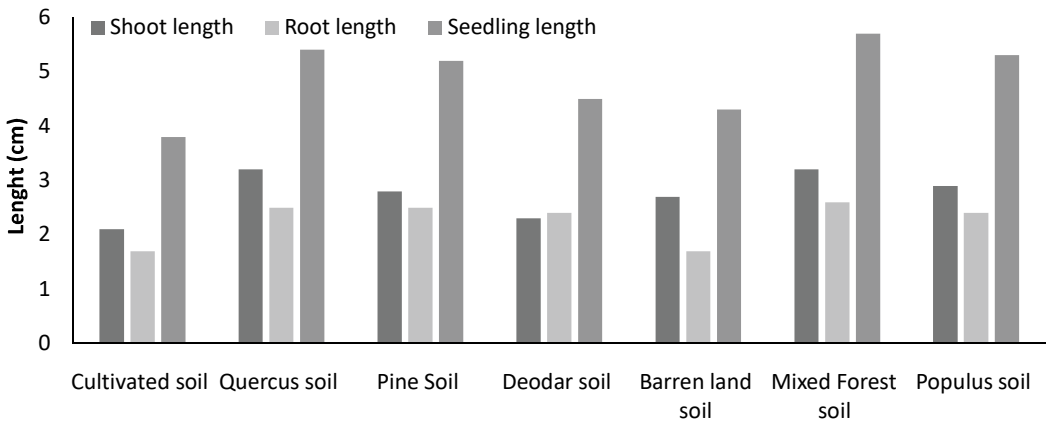


Table 1. Effect of different soil types on daily germination, shoot length, root length, and seedling length

Treatments	Day 1 (cm)	Day 2 (cm)	Day 3 (cm)	Day 4 (cm)	Standard Germination (%)	Mean daily germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)
Cultivated soil	3	6.7	8	8.7	86.7	1.2	2.1	1.7	3.8
Quercus soil	1	6.3	7.7	8.7	86.7	1.2	3.2	2.5	5.4
Pine soil	1.3	7.3	8.3	8.3	83.3	1.2	2.8	2.5	5.2
Deodar soil	0	6	7.3	7.7	76.7	1.1	2.3	2.4	4.5
Barren soil	2.3	6.3	8.7	9	90	1.2	2.7	1.7	4.3
Mixed forest soil	1.7	8.3	9.7	9.7	96.7	1.4	3.2	2.6	5.7
Populus soil	4	8.3	9.7	9.7	96.7	1.4	2.9	2.4	5.3
CD (p=0.05)	1.1381	0.8224	0.8039	0.6189	6.1394	0.0971	0.3594	0.3311	0.5921
CV	0.6477	0.1265	0.1024	0.0758	0.0753	0.0845	0.1417	0.1586	0.1310

Table 2. Effect of different soil types on fresh weight, dry weight, moisture content, seed vigour index and mortality rate

Treatments	Fresh weight (gm)	Dry weight (gm)	Moisture content (%)	SVI I	SVI II	Mortality rate (%)
Cultivated soil	31.7	2.3	91.6	328.7	205.3	3.1
Quercus soil	48.9	3	93.9	456.7	171.3	0.7
Pine soil	65.8	8.9	87.8	444.7	816.7	1.8
Deodar soil	58.4	6.1	90.2	349.3	521.3	0
Barren land soil	61.2	7.7	87.1	384.3	707.3	4
Mixed forest soil	66.1	80	88.2	554.7	769	6.4
Populus soil	94.1	13.4	85.8	512.3	1307.3	1.5
CD (p=0.05)	16.23	23.87	2.42	71.69	335.36	1.88
CV	0.29	1.49	0.03	0.18	0.56	0.81

The moisture content of seedlings showed no significant difference among the treatments, but the highest moisture content was observed in quercus soil, while the lowest was in populus soil. Seed vigour index-I showed no significant difference among the treatments, with the highest index observed in mixed forest soil and the lowest in cultivated soil. Seed vigour index-II showed a significant difference among the treatments, with the highest index observed in populus soil and the lowest in quercus soil. The mortality rate showed a significant difference among the treatments, with the highest rate observed in mixed forest soil, comparable to barren land soil, and the lowest in deodar soil. Aufhammer et al (1994) reported that Amaranth emergence was highest in loamy clay soil with 12% moisture while decreasing soil moisture to 5% inhibited emergence. The nature of the soil surface, such as soil crusting, also had a strong impact on Amaranth's emergence.

CONCLUSION

Mixed forest soil and populus soil performed well across various germination and growth parameters, while deodar soil and cultivated soil exhibited lower rates. These findings

provide valuable insights for optimizing agricultural practices and selecting suitable soil types to enhance the productivity of *Amaranthus* crops. Further research is needed to explore additional factors influencing growth and development, such as nutrient availability, pH levels, and environmental conditions. Understanding these factors can contribute to the development of targeted cultivation strategies and improve the overall success of *Amaranthus* cultivation.

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Phyto-sociological Analysis of Waterlogged Saline Lands of Indian Trans-Gangetic Plains

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***Abstract*:** In the present investigation, a phyto-sociological study in managed and abandoned waterlogged saline sites of Trans Indo-Gangetic plains was undertaken. It was pilot location study done in Sonipat district, Haryana which falls under severely affected category of the waterlogged and salinity problem. The study area was grouped into managed and abandoned sites. In managed sites, the dominant tree was *Eucalyptus* planted in block and boundary arrangement. *Prosopis juliflora* (Mesquite) was dominant tree in abandoned sites without any definite planting pattern and accompanied by low values of shrubs and herbages. *Digitaria sanguinalis* (crab grass) showed highest relative density (53.0) and relative value index (153.0) with lowest value of both the indices (0.56 and 50.6) in *Saccharum ravennae* (elephant grass) in managed sites. *Cyanodon dactylon* showed dominance with highest relative density (63.0) and relative value index (163.0) with lowest (14.0 and 114.0) in *Tamarix dioica* (red tamarix) in abandoned sites. Shannon Weiner (0.46) and Simpson (0.58) Indices were higher in managed sites than abandoned ones. Higher degree of richness in flora in managed waterlogged saline sites is equally supported by the higher species value of diversity index (0.02) than abandoned (0.01) sites. The results of the investigation advocate that the managed sites can render better services than the abandoned sites on phyto-sociological aspects in waterlogged saline landscapes. Higher species richness in managed sites can be linked to better outcomes from ecological and economic perspectives.

***Keywords*:** Biodiversity, *Eucalyptus,* Relative density, Species diversity, Waterlogged saline soils

Geogenic processes and anthropogenic factors resulting in the formation of salt affected soils and the adversities of climate change further fuel to its extent that too in new areas. Globally, one billion hectare area falls under salt lands and out of which 1/3rd is irrigated waterlogged in nature. With each year, 1.50 m ha landmass is adding to the total salt affected areas, globally and if this pace will continue then it would spread to 50 per cent of the cultivable lands by 2050 (Hasanuzzaman et al 2014). In India, 6.73 m ha landmass is affected by salinity (Mandal et al 2010). This problem is more intense as the underlain aquifer is of saline and alkaline in nature. Waterlogged soils cover 4.33 per cent area of the total degraded and wastelands of the country (Maji et al 2010). Waterlogging and salinity is cause of concern to the sustainability of irrigated agriculture in irrigation commands as it is engulfing the culturable lands especially in the Trans Indo-Gangetic plains. This problem occupies more than 3.0 m ha area found in 17 Indian states including Andaman Nicobar islands covering inland and coastal salinity. Trans Indo-Gangetic plains are well known for higher productivity owing to its geographical location and inherent parent material. This region is popularly known as the bread basket of India producing nearly 66 per cent of the total food grains covering the fertile states of Punjab, Haryana, Uttar Pradesh, Bihar, plains of Rajasthan as well as the union territories of Chandigarh and Delhi with total area of 11.7 m ha (Sharma et al 2011, Kaskaoutis et al 2014). Poor drainage system and excessive use of ground water is resulting in waterlogging combined with salinity in the region. Particularly in Haryana state the existing and potential waterlogged saline soils lie mainly in inland depression basin covering Rohtak, Jhajjar, Hisar, Bhiwani, Charkhi Dadri, Sonipat and parts of Jind, Fathebad, Sirsa and Palwal districts.

Drainage, a conventional engineering approach is considered as main remedial option to remove excessive water and salts from the rhizosphere coupled with landshaping technologies for reclamation of waterlogged saline soils. However, such approaches are capital intensive with certain environmental concerns. Contrary to this, biological approaches with the capability of drawing down the water table through combined process of absorption, transpiration and translocation can be trusted upon to address the concern of drainage and other issues. The most common tree in biodrainage is *Eucalyptus tereticornis* (Ram et al 2007, Banyal et al 2019). Analysis of the vegetation structure, composition and organization can be achieved with the help of phyto-sociological study of the area to develop the understanding and functional mechanisms of organisms in any community. It is utmost important to design the suitable plant based systems for efficient management with better

outputs through biological approaches especially for salt affected soils. This concept is also applicable to waterlogged saline areas for their biological management by keeping environmental concerns under check. The information about the vegetation structure in natural and man-managed waterlogged saline soils is flimsy and needs comprehensive research. Therefore, the study has been piloted to work on the general vegetation structure to identify the most exacting floral species (trees, shrubs, grasses and others) for ecological rehabilitation besides multifarious economic outputs in waterlogged saline ecologies of the Haryana state.

MATERIAL AND METHODS

Study area: The study was done in three blocks (Mundlana, Kathura and Gohana) of Sonipat district covering managed and abandoned areas suffering with waterlogging and salinity. This district falls under the severely affected waterlogged saline group in the state. The affected blocks of the district were surveyed through transact walk and sites were then randomly selected as per the standard protocols by covering at least 10 per cent of the total affected area for the study (Fig. 1). The selected sites (villages) were Kathura (29°04'47 N, 76°34'53 E) in Kathura block, Jagsi (29°13'48 N, 76°39'48 E) in Mundlana block and Banwasa (29°08'52 N, 76°33'22 E) in Gohana block for detailed phyto-sociological studies. Observations on floral type, abundance, frequency, density and biodiversity were recorded in post monsoon season (September and October, 2022).

Floristic data: Field observations on phyto-sociological aspects was done using the specific quadrat method viz. 10 x 10 m for trees, 5 x 5 m for shrubs and 1 x 1 m for herbs/annuals in each selected sites. Flora naturalized and/or growing in each site was identified on morphological basis using taxonomic references and through the help of locals. The observations on density, frequency and Importance Value Index (IVI) were calculated using the procedure and formula given by Cottam and Curtis (1956) and Misra (1968).

Density and Frequency were calculated using the formula given below:

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Frequency} = \frac{\text{Number of quadrats in which species occur}}{\text{Total number of quadrats}} \times 100$$

The Relative Density, Relative Frequency was calculated using the formula given below:

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Total number of individuals of all the species}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all the species}} \times 100$$

The Relative Importance Value Index (RVI) of grass species was calculated by summing the value of relative density and relative frequency.

RVI = Relative frequency + Relative density

Biodiversity Indices: Shannon-Weiner diversity index and Simpsons' index used to determine the species richness in the study area.

Shannon-Weiner diversity index is calculated using the following equation (Shannon-Weiner 1963):

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

Where H' is the species diversity index, s is the number of species, and

pi is the proportion of individuals of each species belonging to the ith species of the total number of individuals.

Simpsons' diversity index: This was calculated using the formulae given below Simpson (1949):

$D = \sum(n/N)^2$

Where, n is the total number of individuals of a particular species, N is the total number of individuals of all species

Simpson's diversity index (D) = 1- Simpson's Index

Species diversity index (SDI):

$$SDI = \frac{\text{Number of species encountered}}{\text{Total number of individuals of all the species}}$$

RESULTS AND DISCUSSION

The higher species diversity was found in managed sites compared to abandoned sites in the study area. Managed sites showed predominance of *Eucalyptus* based block and boundary plantation models whereas few scattered trees of *Prosopis juliflora* (Mesquite) without any specific planting pattern in abandoned sites (Table 1). *Eucalyptus tereticornis* covered 11.1 per cent of the total area under the sampled

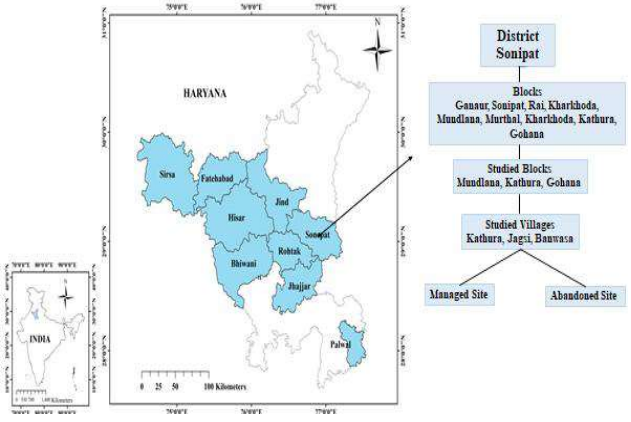

Fig. 1. Scheme of site selection

managed sites. Likewise, *P. juliflora* occupied 8.80 per cent of the area in abandoned waterlogged saline sites. There was no shrub growing on the managed sites owing to the human interventions for higher productive components like trees and agronomical crops. The, salt loving *Tamarix dioica* abundantly grown and occupied about 12.8 per cent of the total sampled area in abandoned sites. Higher species diversity was observed in herbaceous flora in both types of sites. The majority of the herbaceous flora species belongs to grass family. The species wise distribution of annual grass species on both sites are presented in Figure 2 and 3. In total, six grass species (*Cirsium arevense*, *Digitaria sanguinalis*, *Cyanodon dactylon*, *Marsilea quadrifolia*, *Cyantillium cinereum* and *Saccharum ravennae*) were identified from the sampled area under managed sites. All grass species cumulatively covered 88.9 per cent of the total sampled area in the quadrate. *Digitaria sanguinalis* (Crab grass) occupies maximum area (47.0%) among all the six grass species accentuating its wide spread in the study area. The area occupied by other grass species were in the order of 0.50 per cent in *Saccharum ravennae* (Elephant grass) <1.50 per cent in *Cirsium arevense* (creeping thistle) <1.75 per cent in *Cyantillium cinereum* (Little ironweed) <6.25 per cent in *Cynodon dactylon* (bermuda grass) <31.8 per cent in *Marsilea quadrifolia* (Water clover) <47.0 per cent in *Digitaria sanguinalis* (Crab grass) in managed sites. However, only two grass species (Bermuda and nut grass) were found in abandoned sites covering an area of 78.4 per cent of the total sampled area. The area occupied by Bermuda grass was 57.4 per cent and by nut grass was 21.0 per cent from the total covered area by both the grass species, respectively (Table 2). Maximum grass species richness (density) was observed with crab grass followed by water clover and minimum in elephant grass (Table 3). The species wise share was in the order of crab grass (53.0%)> water clover

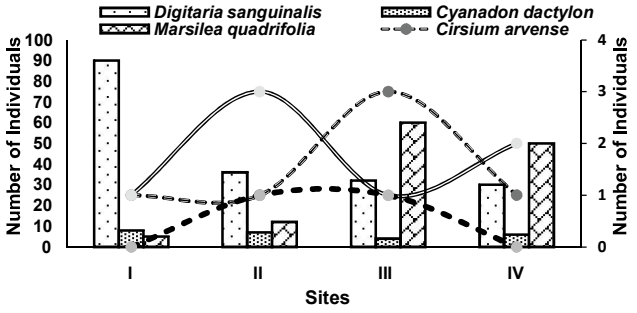

Fig. 2. Species wise distribution of herbaceous flora in managed sites

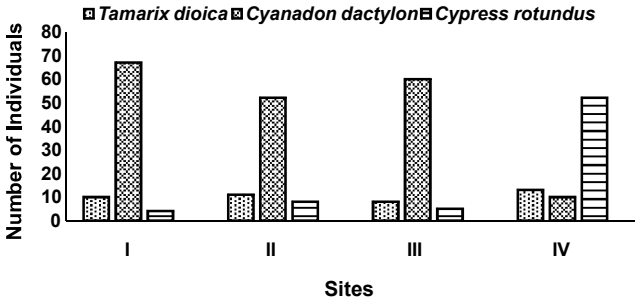

Fig. 3. Species wise distribution of herbaceous flora in abandoned sites

Table 1. Identified flora species in managed and abandoned waterlogged saline sites

Floral diversity		Waterlogged saline sites	
Botanical names	Popular names	Managed sites	Abandoned sites
A. Trees			
Eucalyptus tereticornis	Safeda	+	-
Prosopis juliflora	Mesquite	-	+
B. Shrubs			
Tamarix dioica	Tamarix	-	+
C. Herbaceous flora			
Cirsium arevense	Creeping Thistle	+	-
Digitaria sanguinalis	Crab grass	+	-
Cyanodon dactylon	Bermuda grass	+	+
Marsilea quadrifolia	Water clover	+	-
Cyantillium cinereum	Little ironweed	+	-
Saccharum ravennae	Elephant grass	+	-
Cypress rotundus	Nut grass/Motha	-	+

+ = Present; - = Not present

(35.8%)> bermuda grass (7.04%)> little ironweed (1.97%)> creeping thistle (1.69%) and elephant grass (0.56%), respectively. Further, due to less number of species in abandoned sites, the combined shrub and annual grass species richness (density) was maximum in Bermuda grass followed by nut grass and minimum in tamarix. The share of density was in the order of Bermuda grass (63.0%)> nut grass (23.0%)> tamarix (14.0%), respectively.

The relative frequency of all the grass species in both the managed and abandoned sites was hundred per cent except for Elephant grass which gave 50 per cent value (Table 2). Similar to species richness, the maximum relative density was recorded in Crab grass in managed sites and bermuda grass in abandoned sites. The maximum Relative Value Index (RVI) was observed in crab grass (153.0) followed by water clover (135.8) and the minimum in elephant grass (50.6) in managed sites. However, the highest RVI value was observed in bermuda grass (163.0) and the lowest in tamarix (114.0) in abandoned sites.

Analysis of biodiversity indices provides the information about the social status of the vegetation in community under the studied sites. Overall, comparative site wise indices were derived for both managed and abandoned waterlogged saline sites (Fig. 6). The managed waterlogged saline sites were higher in biodiversity indices value compared to abandoned site with respect to Shannon and Simpson's diversity index. Further, Simpson's diversity index value was lower (0.41) in managed sites than abandoned site (0.47),

Table 2. Area covered (%) with herbaceous floral species in managed and abandoned waterlogged saline sites

Floral diversity		Waterlogged saline sites	
Botanical names	Popular names	Managed sites	Abandoned sites
A. Trees		Area covered (%)	
Eucalyptus tereticornis	Safeda	11.1	-
Prosopis juliflora	Mesquite	-	8.81
	Total	11.1	8.81
B. Shrubs			
Tamarix dioica	Tamarix	-	12.8
C. Herbaceous flora			
Cirsium arevense	Creeping Thistle	1.50	-
Digitaria sanguinalis	Crab grass	47.0	-
Cyanodon dactylon	Bermuda grass	6.25	57.4
Marsilea quadrifolia	Water clover	31.8	-
Cyantillium cinereum	Little ironweed	1.75	-
Saccharum ravennae	Elephant grass	0.50	-
Cypress rotundus	Nut grass/Motha	-	21.0
	Total	88.9	78.4
	Total quadrate sampled area	100	100

Table 3. Phyto-sociological parameters of herbaceous flora growing in waterlogged saline areas

Types of sites	Botanical name	Popular name	Density	Frequency	Relative density	Relative frequency	Relative value Index
Managed sites	*Cirsium arvense*	Creeping thistle	1.50	100	1.69	100	101.7
	Digitaria sanguinalis	Crab grass	47.0	100	53.0	100	153.0
	Cyanadon dactylon	Bermuda grass	6.25	100	7.04	100	107.0
	Marsilea quadrifolia	Water clover	31.8	100	35.8	100	135.8
	Cyantillium cinereum	Little ironweed	1.75	100	1.97	100	102.0
	Saccharum ravennae	Elephant grass	0.50	50.0	0.56	100	50.60
Abandoned sites	*Tamarix dioica*	Tamarix	10.5	100	14.0	100	114.0
	Cyanadon dactylon	Bermuda grass	47.3	100	63.0	100	163.0
	Cypress rotundus	Nut grass/ Motha	17.3	100	23.0	100	123.0

yielding higher diversity in managed site than abandoned sites. Specifically in managed site maximum Shannon-Weiner index was in Water clover (0.16) followed by crab grass (0.15) and elephant grass (0.01). Likewise, Simpson's index value was highest in crab grass (0.28) and lowest in elephant grass (0.00003), illustrating that crab grass emerged as dominant herbaceous species growing managed waterlogged saline sites in Haryana (Fig. 4). In abandoned sites, Shannon-Weiner index was higher (0.15) in nut grass whereas, and Simpson's index in bermuda grass (0.40) (Fig. 5).

Both *E. tereticornis* and *P. juliflora* are phreatophytic tree species which are capable of growing on salt laden soils (Basavaraja et al 2007, Saini et al 2012, Dagar et al 2016, Minhas et al 2020). *Eucalyptus* is the only dominant tree species commonly grown in managed waterlogged saline sites in the study area. Farmers' preferred this species owing to its better phreatophytic nature results in performance in waterlogged saline soils where other tree species can't grow. The other reason for it dominance is the market availability. The other important reason is its higher value in terms of utilization based on time factor as compared to any other tree species in case of waterlogged saline lands (Ram et al 2007, Banyal et al 2019). In abandoned sites, the dominance of *P. juliflora* is beyond any doubt that this is highly tolerant tree species to grow in severely affected waterlogged saline lands. It performs exceptionally well in greening the worlds' dry zones especially saline, alkaline, saline-alkaline (usar) and waterlogged, where no other vegetation exists. Introduction of *P. juliflora* to new areas of the world from its native places North America, South America, Africa and South Asia with a hope to derive analogous benefits from it but it was not as expected. It started spreading and multiplying much faster rate than it was in its natural habitat and turned to be invasive. It has been listed in the world's 100 most dominant invasive plants. This is the reason for its dominance in abandoned waterlogged saline lands. The absence of shrubs in managed sites can be asserted to the intervention by humans as shrubs have no commercial value growing in waterlogged saline sites. However, in abandoned sites shrubs are the dominant component of vegetation structure. It is supported by the findings that Ttmarix is amongst few of the pioneer species tolerant to such harsh situations and can be helpful in initiating the reclamation process for further improvement and utilization of saline landscapes for higher outputs. Vegetation helps in modification of soil properties in terms of physico-chemical attributes in saline landscapes (Duan et al 2022). Joshi et al (2021) also suggested that grasses or herbs exhibit maximum species diversity under and around trees. Crab grass are well known to naturalized in problematic sites and is palatable to livestock adding to its higher utilization value (Jennings et al 2014, Corli and Orsenigo 2022) suggesting that this grass species should have more focus for betterment of waterlogged saline soils in reclamation and output perspectives in managed site. Bermuda grass is well known to salt tolerance thus showed its dominance in abandoned sites with relative value index of 163.0 in the study area. The soil salinity tolerance of bermuda grass goes upto 20.0 dS m^{-1} making it dominant species in abandoned waterlogged saline landscapes (Tran et al 2018).

Presence of such diverse species on both managed and abandoned waterlogged saline sites depict that these sites can be productive upon carrying out certain interventions and efficient management of components. The study clearly depicts that managed sites have an edge over abandoned sites when one compares them on the basis of species diversity. This is supported by the Species Diversity Index of both managed and unmanaged site. The diversity index gave edge to managed site (0.02) over the abandoned (0.01) waterlogged saline.

Waterlogged saline lands are less productive but with proper valuation of the vegetation structure such lands can

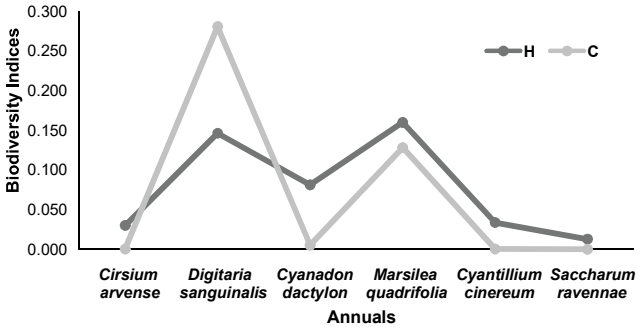

Fig. 4. Biodiversity indices (H-Shanon Weiner and C-Simpson index) of herbaceous flora in managed waterlogged saline sites

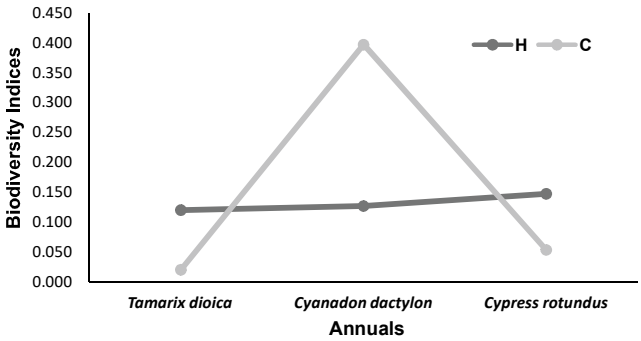

Fig. 5. Biodiversity indices (H-Shanon Weiner and C-Simpson index) of herbaceous flora in abandoned waterlogged saline sites

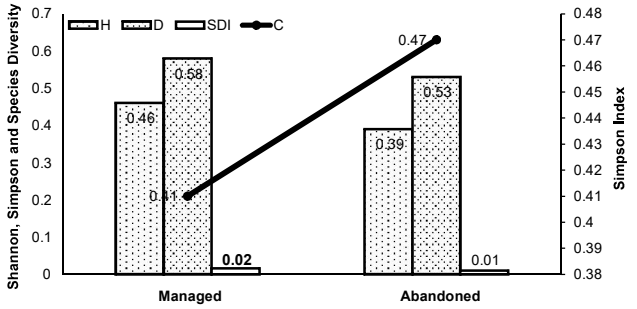

Fig. 6. Biodiversity indices (H-Shanon Weiner, D-Simpson diversity, SDI-Species diversity and C-Simpson index) of waterlogged saline sites

be put to production function by giving focus to the valuable exacting flora in the long run. Managed site has an edge over the abandoned sites in terms of biodiversity that too with valuable species in terms of utilization fronts. The findings are in lines with several theoretical evidences which suggest that greater the biodiversity/species richness on any site the greater would be the related benefits that too with overall ecosystem services (Tilman 2000, Balvanera et al 2006, Cardinale et al 2006, Chaudhari and Pathak 2022). Contrary to this, low diversity gives lesser outcomes in the form of ecosystem services which was observed in abandoned waterlogged saline sites in the study area. The low level of species richness in terms of biodiversity indices in abandoned waterlogged saline sites could be ascribed to the fact that the soil conditions in such sites are not favourable barring few for all type of vegetation. In such situations, only tolerant vegetation can come up that too in sporadic arrangement. In managed waterlogged saline sites, the human interventions for its better management to have higher productivity are the reason for higher floristic biodiversity. The extent of waterlogging and salinity is also less in managed sites than the abandoned sites. Abandoned sites were unattended and remain at the mercy of the nature for its management.

CONCLUSION

The study entrusts in generating a comparable picture of vegetation structure in managed and abandoned waterlogged saline landscapes. The managed site was dominated by *E. tereticornis* in block and boundary plantation models than abandoned site which was dominated by scattered *P. juliflora* trees. Both, managed and abandoned waterlogged saline sites showed variable species diversity index. Crab grass (*Digitaria sanguinalis*) occupied higher share in managed sites. Likewise, bermuda grass (*Cyanadon dactylon*) showed its higher dominance in abandoned waterlogged saline sites. Floristic biodiversity picture would be helpful in laying the protective and remedial management strategies of waterlogged saline lands through bio-reclamation aspects. The promotion of *Eucalyptus tereticornis* especially for abandoned waterlogged saline sites would be more beneficial on time and economic scales.

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Effect of Irrigation Water Salinity Levels on Growth Indicators of Wheat (*Triticum aestivum* L.)

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Abstract: This experiment was conducted in the lathhouse of Basra during the 2021-2020 using plastic pots with a capacity of 5 kg. Three levels of salinity of irrigation water were 1, 3 and 5 $dS.m^{-1}$. The use of irrigation water with increasing levels of saline led to decrease in the average of production of dry weight of the vegetative part. When salinity levels rise (1 to 3 and 5$dS.m^{-1}$), there was decrease in calcium, magnesium and potassium in the plant vegetative part tissues and an increase in sodium and chloride content. The increase in the salinity of the irrigation water decreased the absorbed amount of calcium, magnesium, sodium and potassium and increased chloride absorbed.

Keywords: Salinity level, Irrigation water, Absorption, Element concentration, Wheat

Iraq's geographical location is within the dry and semi-arid areas and the dependence on irrigation in agriculture and the lack of rain and the control of neighboring countries over the headwaters of the Tigris, Euphrates and Shatt al-Arab rivers necessitates the use of saline water and poor quality water in agriculture to compensate for this shortage. Irrigation influence the yield and plays a major role in increasing the readiness to absorb nutrients, in the growth and division of cells and the regularity of the photosynthesis process (Ali and Ahmed 2017). The high concentrations of salts in the irrigation water have direct and indirect effects on the plant leading to reduction in the production of agricultural crops through the toxic effects of sodium ion, which leads to decrease in the effectiveness and activity of cells and their ability to divide (Al Faki 2010). The indirect effects which results in an environment that is not suitable for plant growth and thus affects productivity (Fahad et al 2015). The wheat crop is one of the most important strategic crops in Iraq, as it ranks first in terms of its cultivated area and 4,343.473 million tons annually (Iraqi Ministry of Agriculture 2020), compared to other countries such as Egypt, which produces an average of 8.8 million tons annually (FAO 2018). Therefore, many studies conducted to study the effect of different levels of salinity of irrigation water on the growth and production of wheat. Hussein et al (2011) observed that by increasing the electrical conductivity of irrigation water (4.6 and 9.3 $dS.m^{-1}$), the absorption of nitrogen, phosphorous, potassium, calcium and magnesium decreased, while the absorption of sodium and chloride ions increased in the vegetative growth of wheat with an increase in the salinity of irrigation water. Al Delfi (2013) showed that with an increase in the electrical conductivity (EC) of irrigation water (1.50 and 8 $dS.m^{-1}$) there was an increase in the concentration of magnesium, sodium and chloride, and a decrease in the concentration of potassium, calcium and the percentage of potassium to sodium in the vegetative part of the corn plant. Abboud and Abbas (2013) found that increasing the levels of electrical conductivity (EC) in irrigation water (2, 4 and 8 dSm^{-1}) used for irrigation of wheat and led to an increase in the absorption of sodium, calcium and magnesium, and a decrease in potassium absorption, as well as the ratio of potassium to sodium (K\Na). Al Kaabi (2017) indicated that the increase in the electrical conductivity (EC) of irrigation water (3 and 6 $dS.m^{-1}$) led to a non-significant decrease in the dry weight of the vegetative total of wheat plan. The present study was carried out to obeserve effect of water salinity on the growth of the wheat crop.

MATERIAL AND METHODS

The experiment was conducted in the lath house College of Agriculture, the University of Basra during 2020 using 5 kg plastic pots in completely randomized design with three replications. The physical and chemical properties of the soil used in the experiment were estimated and are presented in table 1. The soil was fertilized with nitrogen @ 200 kg N ha^{-1} in the form of urea fertilizer 46% nitrogen. Nitrogen was added in two batches, day before the date of sowing wheat mixed with the soil and the second after a month from sowing dissolved with irrigation water. Phosphorus was added @ 100 kg P ha^{-1} in the form of concentrated superphosphate fertilizer, 20.21% phosphorous, day before sowing, mixed with the soil, Potassium was added at 120 kg ha^{-1} in the form

of potassium sulfate fertilizer 40.43% potassium at once before sowing, mixed with the soil (Jadoa 1995). Irrigation water was done according to the electrical conductivity in the experiment after preparing a brine solution of known concentration of (MgSO4) salt and diluted to the required salt levels of 1, 3 and 5 dS.m^{-1} by mixing it with distilled water using the following equation (Ayers and Westcot 1985)

$$EC1 = [ECa * a] + [ECb(1-a)]$$

EC1 = Electrical conductivity of the water to be obtained (dS.m^{-1}).

ECa = Electrical conductivity of water used for dilution (dS. m^{-1}).

ECb = Electrical conductivity of drainage water (dS.m^{-1}).

EC1 = Electrical conductivity of water to be obtained (dS.m^{-1}).

a = percentage of water used for dilution (dS.m^{-1}).

The required electrical conductivity values were ascertained by measuring their electrical conductivity after dilution.

Wheat variety Buhooth 22 was sown on November 11, 2020 with 15 seeds per pot and then irrigated with tap water and arranged randomly, covered with black nylon to encourage germination. After germination, thinning was done to keep 10 plants per pot and after ten days were irrigated with the prepared irrigation water levels, in addition, to tap water as a control treatment and equivalent to the field capacity while maintaining moisture in the periodic weight of the pots and completing the deficiency with the same water for each treatment. The experiment continued for 60 days. After 60 days of planting, vegetative part of the plant at were harvested 1.5 cm from above soil surface to avoid contamination. The dry weight of the vegetative growth was calculated by drying the plant samples in an oven at 65-70°C until the weight was stable. The dried plant samples were grounded with an electric grinder, then a certain weight of the plant tissue was taken and digested using an acidic mixture (concentrated sulfuric acid H2SO4 + perchloric HClO4 4%) by heating until a clear solution was obtained according to Purson Cresser method. Sodium and potassium were estimated in the digestion solution using flame photometer rand calcium and magnesium using Phoenix-986 atomic absorption spectrophotometer. The chloride was estimated by taking 0.2 gm of the prepared sample and extracted by (2%) acetic acid, and it was determined by blotting method with 0.01N silver nitrate using 5% potassium chromate index after adjusting the acidity of the extract (Kalra 1998). The absorbable amount of the elements (calcium, magnesium, sodium, potassium and chloride) in the samples was calculated by multiplying the concentration of the element in the plant tissues with the weight of the dry matter of the plant.

RESULTS AND DISCUSSION

Dry matter production (g): The average dry weight of the vegetative part of the wheat plant in response to different salinity levels is depicted in Figure 1. The increase in irrigation water salinity levels from 1 to 3 and 5 dS.m^{-1} led to a significant decrease in the dry matter production of wheat. T1 level was significantly superior to T5 level with dry weight of 14.76 g but it was not significantly superior to the T3 level. This decrease in the dry weight of the vegetative part of wheat with the increase in the salinity can be due to negative effect on the vital processes such as photosynthesis, protein synthesis, and the reduction of total soluble sugars, affecting vital activities and consequently decrease the dry weight of the plant (Bernstein 2011). The increase in salinity levels in the irrigation water has harmful effects on the growth of crop plants due to its osmotic and watery effect of the plant and consequently decrease the growth. Khan (2013) observed that the increase in the salinity of irrigation water leads to high osmotic pressure in the soil solution as a result of the accumulation of salts in the root zone, and consequently, the lack of water availability for the plant as a result of low water

Table 1. Chemical and physical properties of soil before planting

Traits		Values	Units
pH (1:1)		7.30	——
Electrical conductivity (EC)		3.45	dS.m^{-1}
Organic matter		11.4	g.kg^{-1}
Dissolved ions	Ca^{2+}	6.6	mmol.L^{-1}
	Mg^{2+}	4.0	
	Na^{+}	16.1	
	K^{+}	2.2	
	Cl^{-}	22.3	
	$SO_4^{=}$	7.1	
	CO_3^{-}	0.0	
	HCO_3^{-}	2.1	
	SAR	4.94	
Soil separators	Clay	390.0	g.kg^{-1}
	silt	317.3	
	sand	292.7	
Soil texture		Clay Loam	——

Table 2. Effect of irrigation water salinity levels on the concentration of ions in wheat (%)

Salinity levels (dS m^{-1})	Ion concentration (%) in wheat				
	Cl	K	Na	Mg	Ca
T1: 1	0.70	1.27	1.80	0.60	1.53
T3: 3	1.01	1.25	1.88	0.55	1.40
T5: 5	1.21	1.01	1.94	0.50	1.06
Control	0.53	1.28	1.05	0.35	1.40
CD (p=0.05)	0.61*	0.36ns	0.23**	0.35ns	0.23**

potential. This causes physiological thirst of the plant despite the availability of water in the soil. These results agree with the findings of earlier workers (Rajpar et al 2011, Yassin et al 2011, Al Shammari 2012 and Eissa et al 2018).

Effect of irrigation water salinity levels on the concentration of ions: The increase in the salinity levels of irrigation water reduce calcium content. There were highly significant differences in T1 and T3 compared to the salinity level T5. Ali (2012) observed that the nutritional balance within the plant is directly related to the presence of Ions of some elements of the salts in the soil solution. Al-Shammari (2012) concluded that the increased salinity led to a reduction in calcium, magnesium, and potassium, and an increase in sodium in vegetative parts of wheat plant.

There were non-significant differences for the increase in salinity levels in the concentration of magnesium in plant and it decreased from 0.60 to 0.55 and 0.50% for levels T1, T3 and T5, respectively, compared to control treatment (0.35%). The highest concentration of sodium was at T5 (1.94%), while the levels T3 and T1 recorded an average concentration of 1.88 and 1.80%, respectively. The potassium concentration in the vegetative part of the wheat indicated that there were no significant differences due to imposed salinity levels through irrigation water. The potassium concentration decreased from 1.27 to 1.25 and 1.01% with an increase in the salinity levels of irrigation water from T1 to T3 and T5, respectively. Al Delfi (2013) explained the decrease in potassium concentration in plant tissues with increasing salinity of irrigation water decrease the growth due to obstruction in absorption of ions by the plant, including potassium. The results indicated that the chloride concentration in the vegetative part of the wheat plant increased with an increase in the salinity levels however were no significant differences. The results agree with the findings of Al Shammari (2012), Shamsi and Kobaraee (2013) and Al Kaabi (2017).

Ions absorbed in the wheat plant (g): The highest amount of Ca absorption was in the control treatment (243.18 g) followed by T1, T3 and T5 with a decrease in the amount of calcium absorbed by 7.13, 20.78 and 51.62% compared to the control treatment (Table 3). Ragab et al (2008) observed that low absorption of nutrients by plants is that plants exposed to salinity spend most of their energy in osmotic regulation of water withdrawal from the external environment, which causes an imbalance in the absorption of nutrients.

There were no significant differences for the increase in the levels of salinity of irrigation water in the absorbed amount of magnesium. The lowest absorbed amount was recorded by the saline level of 5 $dS.m^{-1}$, while the control treatment achieved 60.79 g of the absorbed amount of magnesium in wheat plant. Al Zubaidi (2011) indicated that each element has a specific function in the vital processes that take place in different plants, and when an element is greatly increased or decreased, this causes an imbalance in one of the bio processes. Sodium absorbed in the vegetative part of the wheat plant was significant in at salinity levels T1 and T3 compared with the control treatment. Sodium decreased with the increase in the salinity levels of the irrigation water, with a decrease of 2.63, 18.95 and 31.35% for the levels T3 and T5 and the control treatment, respectively, compared to the T1 level. The lowest absorbed amount of sodium was in control treatment (182.38 g), while the highest amount was absorbed at the T1 level (265.68 g). This may be because the salinity of the irrigation water causes an imbalance in the nutritional balance in the soil and plants, as well as the effect of salinity on the phenomenon of preference for plants to absorb the required nutrients (Al Zubaidi 2011). The concentration of salts in the soil causes competition between the salt ions and the ions needed by the plant, as the plant absorbs ions with high salt concentrations than required for metabolic processes (Verbruggen and Hermans 2013). There were no significant differences in the absorbed amount of chloride, but the increase in the levels caused an increase in the absorbed amount of chloride, reaching 103.32, 138.97 and 134.31% for levels T1, T3 and T5,

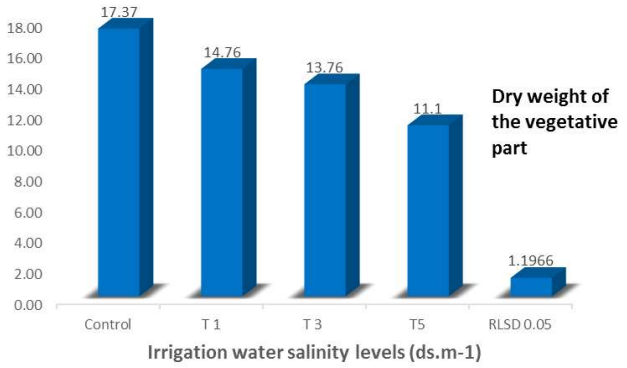

Fig. 1. Effect of irrigation water salinity levels on the dry weight of wheat (g)

Table 3. Effect of irrigation water salinity levels on the amount absorbed by wheat (g)

Salinity levels ($dS\ m^{-1}$)	Absorbed amount (mg) in wheat				
	Cl	K	Na	Mg	Ca
T1:1	103.32	187.45	265.68	88.56	225.83
T3:3	138.97	172.00	258.69	75.68	192.64
T5:5	134.31	112.11	215.34	55.50	117.66
Control	90.06	222.34	182.38	60.79	243.18
RLSD	51.66ns	60.53**	52.99**	33.50ns	33.72**

respectively. In control treatment, the lowest amount of chloride ion was absorbed (90.06 g). In general, these results agree with the findings of Al Ghurairi (2011) and Hussein et al (2011) that increasing the salinity of water irrigation led to decreased absorption of calcium, magnesium and potassium. Abboud and Abbas (2013) however, observed that the increase in the salinity of irrigation water led to an increase in the absorption of sodium, calcium and magnesium and a decrease in the absorption of potassium.

CONCLUSION

This study indicated that increased and frequent saline water irrigation resulted in gradual salt accumulation in the soil, which negatively affected growth of wheat plant as a result of low absorption of the ions needed by the plant.

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Mycoremediation of Cd and Pb from Contaminated Soil using Arbuscular Mycorrhiza *Glomus leptotichum*

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Abstract: The objective of study was to investigate the possibility of utilization of arbucular mycorrhizae (AM) to clean up the soil contaminated with two heavy metals, Cd and Pb using sunflower plants (*Helianthus annuus*) as a test plants. AM fungi used was *Glomus leptotichum*. Study was carried out under controlled conditions and sterilized soil. There was significant increase in dry weight of the root system of the AM inoculated plants compared to the negative control . The results showed variable effect of heavy metals on the dry weight of shoot system. Root and shoot dry weight, in response to increasing concentrations of heavy metals applied to the soil, had a significant adverse or negative effect of Cd and non significant effect at the concentration 50 and 100 ppm of Pb on plants inoculated with AM fungi. The AM showed high efficiency for extraction of these heavy metals from the soil at low concentrations and reduction of this efficiency at high concentrations. Compared to shoot rate of accumulation was almost five times lower than the roots. The rate of Cd accumulation in the seeds of the plant was within the toxic levels and recorded 12.9 ppm. in the plants inoculated with *G. leptotichum*. This indicates the efficiency of this AM species to remove this metal from the soil, i.e. within the toxic levels and probably present a risk to human health.

***Keywords*:** Vesicular mycorrhizae, Heavy metals, Glomus *leptotichum*, Cd, Pb

Environmental systems are polluted with heavy metals due to industrial and electronic waste, including cadmium (Cd) and lead (Pb), which cause harm to public health. These heavy elements cannot be converted by plants into a non-toxic form inside their cells and they bind with soil particles and ions to form insoluble complexes and sediments. It may be part of the composition of silicates in the soil (Cobbett and Goldsbrough 2000). The process of biological extraction is used including maycorrhizal fungi that encourage the extraction of cadmium, lead and other elements through the colonization at the root of the various families including the sunflower (Chandrashekara et al 1995, Joner and Leyval 1997, Hossein 2010, Gaur and Adholeya 2004). There are other microorganisms which play a role in these systems including nitrogen-fixing bacteria, fungi, yeasts and others. The arbuscular mycorrhiza fungi (AM) is a type of the soil microorganisms that create a symbiotic relationship with most of the plants to ensure that physically remain connected directly between the soil and plant roots. The sunflower plants incurred for the collection and accumulation of heavy metals (Davies et al 2001). Hence the aim of this research was to study the role of *Glomus leptotichum* in the absorption and accumulation of heavy metals in different parts of the plant and its role in cleaning up the environment biologically.

MATERİAL AND METHODS

Bio-fertilizer starter culture: The stock inoculum containing *G. leptotichum* spores with dry sand soil was used in the study. To ensure the presence of fungal spores, the method of wet sieving was used. The activation process was conducted using a sterile sand soil by autoclave for three hours and 121^{0}C and pressure of 15 Ib. in^{-1} and dried in an electric oven at 60^{0}C until drying. The efficiency of sterilization tested by taking sample of each batch and cultured in nutrient broth and incubated 30 and 37^{0}C. Sterile soil was distributed in plastic pots, 1kg soil each. Fifty grams of AM inoculum (starter fungal fertilizer) added by pad method 3 cm depth and covered with a similar amount of soil in pots of each treatment (Mosse and Hepper 1975). The field capacity of pots containing sterile soil and a nutrient solution of stocks containing the necessary nutrients were measured (Davies et al 2002).

Onions bulb as the host plant was sterilized by 95% ethanol and 2% mercuric chloride and washed several times with sterile distilled water to remove disinfectant traces. This bulb was transplanted in the pots contained 1 kg sterile sand soil with three bulbs for each and added 200 m nutrient solution to soil , before two days of planting. Two weeks after planting, another 200 ml of the nutrient solution was added to each pot (Davies et al 2001). After four months the shoot removed, and the soil with chopped roots was air dried in trays and then keept in sterile plastic bags in a cool and dry place until use as a stock culture. The roots of the onions were stained using acid fuchsin dye (Kormanik et al 1980).

The percentage of infected roots with mycorrhizal fungi were accounted (Davies et al 2002).

$$\text{Percentage of colonization} = \frac{\text{Total colonized with AM - Total non-colonized}}{\text{Total non-colonized}} \times 100$$

Sand soil was dried and passed through 2 mm diameter sieve and washed with water to remove most of the organic matter and fertilizer (Davies and Linderman 1991). The soil was sterilized by autoclave for 3 hours and 121 ^{0}C and pressure of 15 lb. in^{-1}. The amount of phosphate, total nitrogen and heavy metals in the soil were estimated (Table 1).

Heavy metal solution: This was prepared as suggested by Chandrashekara et al (1995). Implemented a full factorial sectors of randomization experiment (RCBD) using two types of heavy metals in four concentrations (Table 2). The plastic pot was filled with 3 kg sterile sand soil, chemical fertilizers were added (Davies et al 2002). The 15g of mycorrhizal fertilizer was added to each pot by pad technique (Mosse and Hepper 1975). Five sterile seeds of sun flower were sown in pot after the addition of nutrient solution and irrigated with 200 ml of sterile water and Cd and Pb were added, according to the concentrations listed in the experimental design. Plants were harvested after four months and then cut off the shoot at soil surface level and dried in an electric oven at 60 ^{0}C for 48 hours. The roots were washed well and dried by using the same method.

Table 1. Available phosphate, total nitrogen and heavy metals in the soil

pH	7.58
Available phosphate	0.9 gm Kg^{-1}
Total nitrogen	1.7 gm Kg^{-1}
Cd	Nil
Pb	6 ppm

Analysis of the soil after the harvest: Soil N and P content was estimated for all treatments (Bremner and Mulvaney1982, Watanable and Olsen 1965). The total heavy metals (Cd and Pb) were analyzed by flame atomic absorption photometer (Kumpulainen and Paakki 1987).

Plant analysis after harvest: Shoot, root and seed samples were analyzed to estimate total nitrogen, total phosphorous, cadmium and lead in all treatments as per procedure suggested by McKeague (1978).

Impact of heavy elements in the dry weight: Fresh shoot, root and seed samples washed with water were dried separately in an electric oven 60^{0}C till constant weight to calculate dry weight. The mycorrhizal conducting dependency, which is a plant dependent on AM when the value of mycorrhizal dependency higher than 50% (Davies et al 2001).

RESULTS AND DISCUSSION

The onion was used as host plant for activating mycorrhizal fungi through infected root. The pad technique was used to add myco-fertilizer, which helps to inoculate the onion bulb near *Glomus leptotichum* propgules which thereby increases the chance of colonization on roots with AM (Owusn,-Bennoah and Mosse 1979). *Glomus leptotichum* succeeded in infecting the roots of onions plant and when stained with acid fuchsin dye, infection rate was 70-80% when propagule structures was examined under optical microscope.

Cadmium treatment: The results in treatment 20 ppm of Cd indicate that *G. leptotichum* showed higher efficiency in extracting Cd from the soil and that this differential impact perhaps because of genetic differences for AM fungi which led to the difference in efficiency of AM infection in the soil contaminated with heavy metals and toxic effects (Chandrashekara et al 1995). AM have an additional role in increasing the accumulation of heavy metals in the plant and this is consistent with the findings of Joner and Leyval (1997)

Table 2. Treatments and heavy metals concentration and mycorrhizal fungi used in this study

Treatment	Fungal treatment	Heavy metal
1	Negative control (- AM)	-H.M.
2	Positive control (+ AM)	-H.M.
3	+ AM	Cd concentration of 0.15 is equivalent to 1 mg kg $^{-1}$ of CdSO4.8H2O
4	+ AM	Cd concentration of 1.5 is equivalent to 10 mg kg $^{-1}$ of CdSO4.8H2O
5	+ AM	Cd concentration of 3.0 is equivalent to 20 g kg $^{-1}$ of CdSO4.8H2O
6	+ AM	Cd concentration of 6.0 is equivalent to 40g kg $^{-1}$ of CdSO4.8H2O
7	+ AM	Pb concentration of 7 equivalent to 12.5 mg kg $^{-1}$ of (CH3COO)Pb.3H2O
8	+ AM	Pb concentration of 14 equivalent to 25 g kg $^{-1}$ of (CH3COO)Pb.3H2O
9	+ AM	Pb concentration of 28, equivalent to 50 g kg $^{-1}$ of (CH3COO)Pb.3H2O
10	+ AM	Pb concentration of 56 equivalent to 100 mg kg $^{-1}$ of (CH3COO)Pb.3H2O

who observed that extraradical hyphae for AM fungi is responsible for the transfer of Cd from soil to plant. This also increased the amount of phosphorus at concentrations 1 and 10 ppm of Cd in roots inoculated with *G. leptotichum*, which indicates not affected by taking phosphorus added Cd.

Low phosphorus content in the roots was 0.57 g kg^{-1}, and about 0.7 g kg^{-1} in the positive control which treated with *G. leptotichum*. This indicates the effectivity of AM to increase the availability of phosphorus.The total phosphorus content in the shoot increased from 1.7 to 4.5 g kg^{-1} at AM fertilization with *G. leptotichum* but different concentrations of Cd resulted in decrease to 2.5 g kg^{-1}, although it remained higher than the phosphorus content in the negative control, which indicates the effectiveness of AM. Rivera-Becerril et al (2002) observed no significant difference between mycorrhizal plants with phosphorus content when treatment with Cd.

The accumulation of cadmium in the soil and its association is non-motile in the alkaline soil may be a change in the level in various concentrations due to the AM action (Fig. 1), working to extract ingredients from the soil and transported to the plant. The reason for the survival of large amounts of cadmium in the soil due to the impact of the toxic activity and effectiveness of AM in disrupting mechanical bio-extraction. The results indicate that the transaction *G. leptotichum* showed higher efficiency in extracting Cd from the soil in the low concentrations rather than in high concentrations (Chandrashekara et al 1995). The findings show significant differences in cadmium transactions which increased in the positive control. The accumulation of this metal in the shoot in spite of this part of the plant is not a nutritional importance due to the lack of nutrients and large number of fibers with a lack of content protein but that refers to the transmission element from the soil to the roots and shoot because of the presence of genetic tankers like AtNramp3 which transport cadmium and collects in the food vacuoles in the shoot as well as TgMIP1 tankers that transport cadmium to the leaf vacuoles and tankers TcZNT1 that transport cadmium to the shoot also, but the amount is less than the accumulated in the roots (Hall and Williams 2003). The amount of cadmium accumulated in the roots with shoot, indicate that the roots contain about 5 times more amount than the shoot and these results are consistent with Rivera-Becerril et al (2002). The studies of mycorrhiza type *G. intrakadisces* with *Pisum satium* indicated that cadmium accumulates in the roots 20-50 times more than the shoot, and existence of several plant species stand in front of the transfer of cadmium to shoot and this behavior is one of several strategies to accumulate pollutants. Mycorrhizal fungi play an additional role in increasing the accumulation of heavy metals in the plant. The mycorrhizal extraradical hyphae is responsible for the transfer of cadmium from soil (Zhitong et al 2012). The variation in the accumulation of cadmium in the seed was maximum 7.5 ppm/ seed weight treated with *G. leptotichum*, which showed high efficiency in the extraction of cadmium and then moving to the seeds, and exceeds the limit, which ranges between 0.05-0.2 ppm, and up to toxic ranging limit 5-30 ppm, when compared with the amounts of cadmium accumulated in the roots and seeds with the shoot parts. The cadmium did not arrive to the seeds (Fig. 1). It was explained by the existence of a strategy to link the heavy metals with the cell wall of roots and shoots, which reduces the concentrations of these elements in the seeds. There are other mechanical plants tolerant to the toxicity of heavy metals depends on detoxification and the secretion of substances to cells vacuoles by metallothioneins molecules and phytochelatins (Cobbett and Goldsbrough 2000, Cobbett 2000).

The dry weight of roots and shoot of the sunflower has dropped significantly when comparing fungi and concentration of heavy metal which refers to the inhibitory effect of cadmium on the shoot (Table 3). The result showed that treatment of AM with high toxicity of cadmium, colonization decreased and led to a significant inhibition of the growth of shoot compared to its influence on root, which was evident in the growth during the study period where plant's dependence on AM and accompanied by atrophy of the shoot of high toxicity at high concentrations of cadmium. High concentration of heavy metals in soil have an adverse effect on AM fungi and microbial processes due to thier toxicity for living organisims (Sergio et al 2012). Davies et al (2001) also observed that this has negative relationship with heavy metals. But the treatment plants of different concentrations of cadmium display slight impact of the *G. leptotichum* indicating significant changes in vital operations and photosynthesis because of heavy metals contamination.

The percentage of positive control with the dependency of the plant on AM fungi, was 109.4%, while the plants which treated with cadmium in the treatment with AM dependency on AM the percentage dropped to 33.5% and reached the highest level cadmium concentration of 40 ppm (Table 3).

Lead treatment: *G. leptotichum* was highly effective in the availability of shoot phosphorus and increased efficiency in the concentration of 12.5 ppm. Very ambiguous, only author can tell what he want to say. This had reached to maximum effect 100 ppm concentration. The figure 2 shows that AM fungi have highly efficient in taking the lead from the soil where they were drawn tainted completely in the first concentration 12.5 ppm, in addition to what is present in 6

ppm and continued efficiency even at the highest concentration of 100 ppm. The amount of lead in the roots increased with increasing concentrations and with a significant effect for the type *G. leptotichum*, despite the fact that there is a genetic sole which limit transmission of lead, a known channels (GNGC) (Fig. 2). These channels transporting lead through the plasma membrane into the cell and is working to accumulate inside the plant cells, where the results of the current study, agreed with the findings. The viability of accumulative high in the tissues of plant roots to lead, reaching the highest accumulative amount of lead 212.5 µg/gm dry weight and this amount is within the limits allowed globally. There was non significant increase in the shoot between the positive control and negative control which refers to the positive impact of fungi AM. Gaur and Adholeya (2004) observed that *G. mossese* has weak susceptibility to compile lead in the vegetative part. The increase the surface absorption by extended hyphea in addition to the root hairs form a barrier against the transfer of heavy metals into the plant shoot. At the genetic level, the responsibility for the transfer of lead into the cells through the plasma membrane is GNGC channels that play a key role in the accumulation of lead in the plant process (Gaur and Adholeya 2004). There is a high percentage of lead up to 85 ppm accumulated in the sun flower seeds (Fig. 2). This is within the acceptable limits determined by international standards 30-300 ppm which is not considered harmful to public health when ingested directly by human food or animal feed (Medina et al 2003).

The root dry weight of the positive control may outweigh the negative control and that may be due to the influence of AM fungi the root to increase the surface area for the absorption of reflecting on the obvious differences in dry weight of shoots by AM fungi. Dry weight also increased in roots inoculated with *G.leptotichum* treatments 12.5 and 25 ppm due to increased dry weight of the root compared with shoot due to the toxic effects of lead. In plants treated with different concentrations of lead the shoot showed an increase in the content of the total nitrogen in the fertilized treatment with *G. leptotichum* especially in 12.5 ppm concentration and then started to decrease to concentration 100 ppm reached 0.93. The results of AM myccorhizal dependency index indicte that the toxicity of lead to sunflower at higher concentration influenced shoot root ratio compared to the negative control. The percentage of the effect of AM may be zero in all treatments suggesting AM failed to infection due to the toxic effect of lead on the AM fungi. But when inoculated with *G.leptotichum* plants in the positive control and was dependent on AM fungi (109.4%), but when added the lead concentration 12.5 ppm and other concentrations to 100 ppm, plant was not supported on AM even with independency ratio of 6.1%.

Table 3. Effect of different concentrations of cadmium in the dry weight of sunflower (*Helianthus annuus*) infected by AM fungi type *G. leptotichum*

Cadmium treatment/ ppm	Shoot (g dry weight)	Root (g dry weight)	Total plant (g dry weight)	Mycorrhizal dependency (%)	Root/shoot ratio (%)
Negative control	3.51	0.42	3.93	---	0.12
Positive control	7.33	0.9	8.23	109.414	0.123
1	4.75	0.5	5.25	33.587	0.105
10	4.35	0.46	4.81	22.391	0.106
20	4.51	0.37	4.88	24.173	0.082
40	2.45	0.34	2.79	-29.007	0.139

Table 4. Effect of different concentrations of lead in the dry weight of the plant sunflower (*Helianthus annuus*) infected with AM fungi type *G. leptotichum*

Cadmium treatment/ ppm	Shoot (g dry weight)	Root (g dry weight)	Total plant (g dry weight)	Mycorrhizal dependency (%)	Root/shoot ratio (%)
Negative control	3.51	0.42	3.93	---	0.12
Positive control	7.33	0.9	8.23	109.414	0.123
12.5	4.4	0.7	5.1	29.77	0.159
25	4.19	0.66	4.85	23.409	0.157
50	3.98	0.62	4.6	17.048	0.155
100	3.14	0.55	3.69	-6.106	0.175

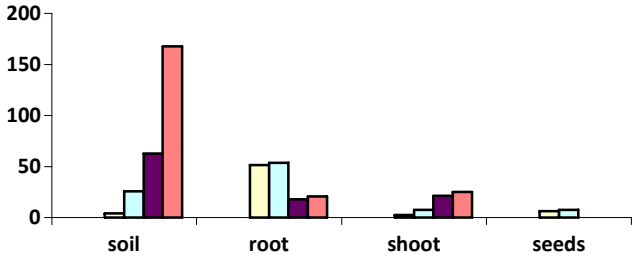

Fig. 1. Concentration of cadmium accumulated rates in the soil, roots, shoot and seeds sunflower plants inoculated with AM fungi

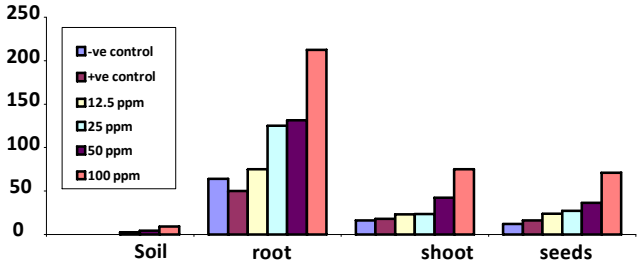

Fig. 2. The concentration of lead accumulated in the soil, the roots, the vegetative parts and sunflower seeds and in plants inoculated with VAM fungi

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Surface Water Mapping using Google Earth Engine (GEE) for South Gujarat Forest

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Abstract: The spatial and temporal changes in surface water area were analyzed in Dang district of south Gujarat. The time series of normalized difference water index (NDWI) with Google earth engine (GEE) open source online planetary processing platform was used. Spatial distribution precipitation, LST, NDVI and ETa were also analyzed. The surface water availability showed high positive correlation with precipitation (0.76), LST (0.93) and ET_a (0.90). The surface water availability varied month wise, minimum surface water area was observed in May while maximum in January. Availability of surface water increases NDVI and ETa thus decrease LST and *vice-versa*.Present results would be helpful to planner and forest department to make decisions for water conservation activities in forest area.

Keywords: Remote sensing, Surface water, Forest hydrology, Water conservation

Surface water in forests plays an important role in regulating local and regional climates by influencing temperature, humidity, and precipitation patterns. Surface water is essential for maintaining the forest ecosystem health and biodiversity, and regulating a range of ecological processes in turn provides several services. Water bodies need to be analysed and monitored consistently for efficient management of the forest water resources. Precise spatial and temporal information of surface water in forest area gives vital data for forest hydrology, planning of water conservation structures, providing crucial knowledge for preparing of water hole in forest for wild animal and assisting in the monitoring water-based ecosystems. Changes in forest cover, water yield and evapotranspiration can alter surface water dynamics (Bruijnzeel 2004, Jackson et al 2009).

Effective methods are important for monitoring the spatial and temporal changes in surface water which can analysed by remote sensing technologies as remote sensing is far more effective than conventional *in situ* measurements since it can continually track the Earth's surface at various scales (Huang et al 2018). This has emerged as a cutting-edge technology method for quickly obtaining water information because of its benefits of real-time, extensive coverage, and comprehensive information (Li et al 2022). Water indices, which are derived from two or more bands and used to distinguish between water and non-water areas, has been a quick and efficient technique to extract water (Huang et al 2018). Normalized difference water index (NDWI) derived from satellite images are commonly and successfully utilized in surface water body detection and mapping (Du et al 2014, Özelkan 2020). NDWI was used to detect the surface water bodies in parts of Upper Krishna River basin, Maharashtra State of India (Ashtekar et al 2019). However, this type of analytical operations needs specific high-end software and voluminous downloaded data sets to create desired output which is time cumbersome process. Therefore, high-performance data computing platforms based in the cloud, like Google Earth Engine (GEE), have emerged as better alternative options. Moreover, this platform's impressive satellite image archives, coupled with sophisticated in-built processing and analyzing toolkits, immensely help remote sensing-based studies. Now a day GEE is widely used (Amani et al 2020) in various study such as land use land cover change (Sidhu et al 2018), wetland inventory (Amani et al 2019), crop land mapping (Xiong et al 2017), irrigated area mapping (Magidi et al 2021), flood monitoring (DeVries et al 2020), water bathymetry mapping (Li et al 2021), forest monitoring (Jahromi et al 2021 and Piao et al 2022), costal ecosystem assessment (Wang et al 2020) and drought assessment (Sazib et al 2018). The availability of water bodies has changed over time and space, and the scarcity of water resources is getting worse in the south Gujarat forest area, as a result, the monitoring of water bodies is indispensable. Even though the Dang district receiving highest rainfall than other district of Gujarat, but it is experiencing low availability of surface water particularly during dry months. Hence, the present study aims to delineate and assess the spatial and temporal change in surface water of dang district using the Google earth engine.

MATERIAL AND METHODS

Study area: The study was conducted in the Dang district, which fall in the heavy rainfall zone of the southern part of Gujarat (Fig. 1). The Dang is a hilly district, primarily populated by tribal people and located in eastern part of the western Ghat of India. It has the highest forest density (77.16%) in the state and covers an area of 1766 km^2 (ISFR, 2019).

Data used: Sentinel 2 satellite data was used for assessing spatial and temporal change in surface water body. QGIS software and Google earth engine were used for NDWI index generation, classification and extract water bodies. Other climatic parameters were derived for the study area using climate engine (Huntington et al 2017). The detail of the data used in the study is given in Table 1.

The images were accessed from the GEE platform (https://earthengine.google.org/). The images were geometrically referenced and were top-of-atmosphere (TOA) images. While constructing the image archive, a cloud filter criterion of 10% was implemented across region of interest (ROI). Further, for more precise construction of the data achieve, monthly median data was generated along with mosaic data sets for the ROI. The standard code for delineation of water surface body was written using java script for cloud computing in Google earth engine. The flow chart of surface water mapping is shown in Figure 2.

NDWI is calculated with the following equation.

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

where, the B3 band represents the green band for sentinel 2 images, while the B8 band represents the NIR band. This study, for each NDWI calculated, pixels with NDWI >0 were considered water and pixels with NDWI ≤0 were marked as non-water.

In addition, climatic parameters were derived for the study area from climate engine from 2016 to 2022. The MODIS land surface temperature, NDVI and were converted into annual data where as CHIRPS Precipitation and Actual Evapotranspiration (MODIS SSEBop) data set were daily and converted in to annual data for comparison and correlation with surface water availability.

RESULTS AND DISCUSSION

The extent of surface water body for Dang district during post monsoon month from 2017-2022 estimated using multidate NDWI (Fig. 3, Table 2) indicated that surface water availability varied from month to month and higher surface water area was observed during January month. The lowest surface water was observed in May due to the higher land surface temperature and increases in evapotranspiration the study area. The resultant effect of bioclimatic parameters greatly influence the water surface area during dry months. The availability of surface water in respective months differ due to amount of rainfall, temperature, actual evapotranspiration and other climatic parameters (Table 3).

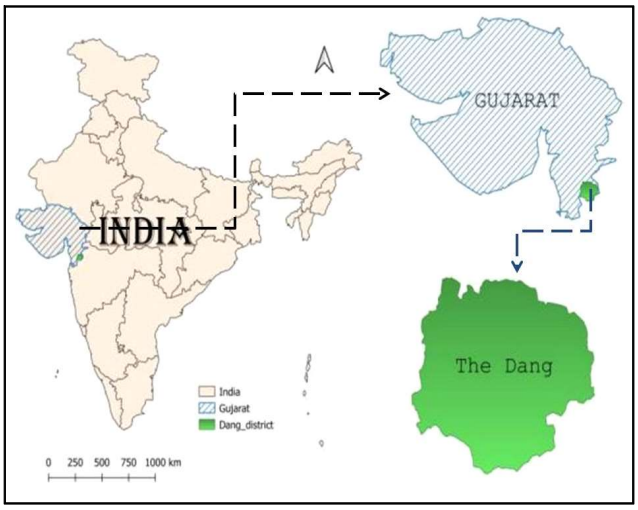

Fig. 1. Location of Dang district

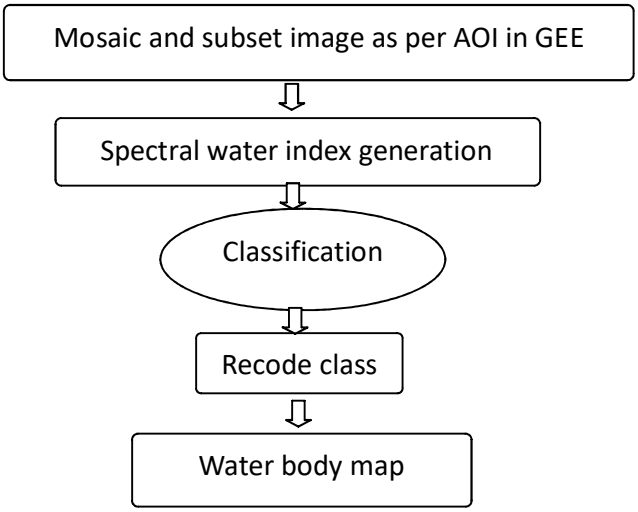

Fig. 2. Schematic for the surface-water mapping

Table 1. Data used for the study

Product	Resolution	Duration
Sentinel 2	10 m	2017-2022
MODIS Terra Daily (LST)	1000 m	2017-2022
MODIS Terra Daily (NDVI)	500 m	2017-2022
CHIRPS Precipitation Daily	4800m	2016-2021
MODIS SSEBop (Actual Evapotranspiration) ET_a	1000 m	2017-2021

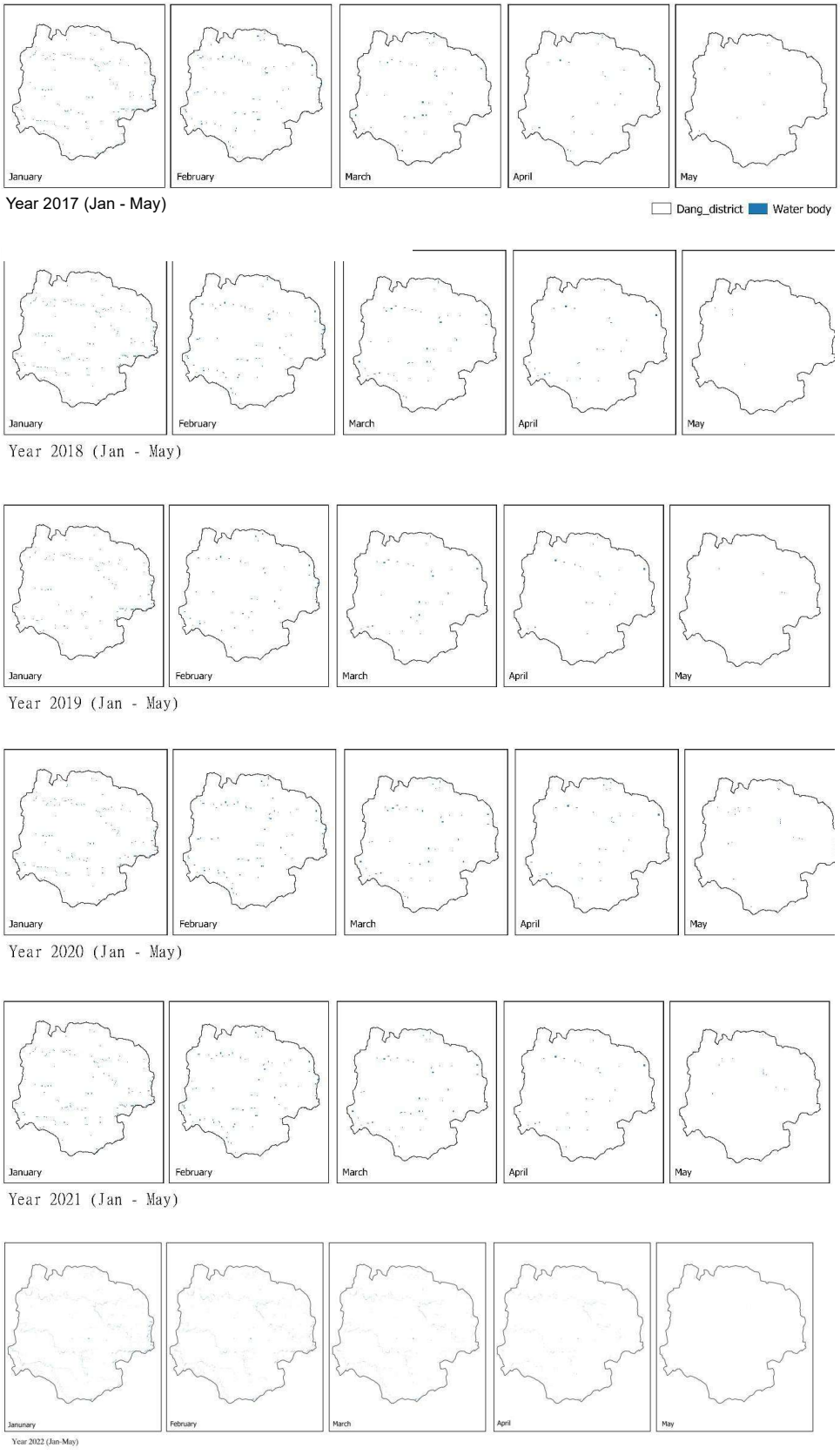

Fig. 3. Spatial and temporal surface water availability map for the year 2017-2022 (Jan-May)

The spatial distribution of the different parameters precipitation, LST, NDVI and ETa are given in Figure 4, 5, 6 and 7, respectively. Vegetation contributes significantly in reduction of LST which indirectly contributed in surface water availability. Interestingly, surface water availability was highly positively correlated with precipitation (0.76), LST (0.93) and ET_a (0.90). It is evident that availability of surface water mainly depends upon the quantity of rainfall occurred during previous year and thus increases NDVI and ETa while reduces LST. The amount of rainfall in previous year is the driven factor affecting the availability of surface water that triggered the increase/decrease LST, NDVI and ETa. For instance, lowest rainfall occurred in the year of 2018 showed higher LST in contrary NDVI and ETa observed lowest in the

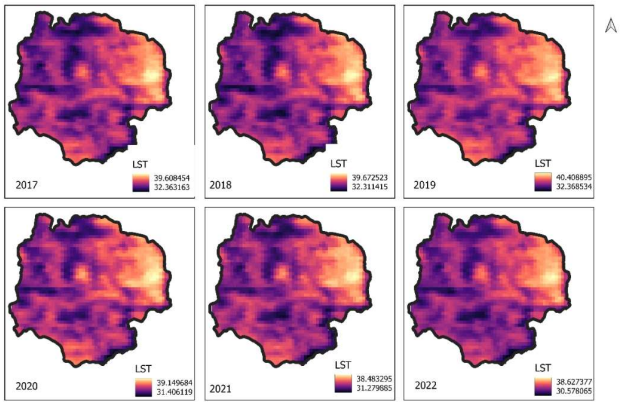

Fig. 5. LST map of the Dang district during year 2017 to 2022

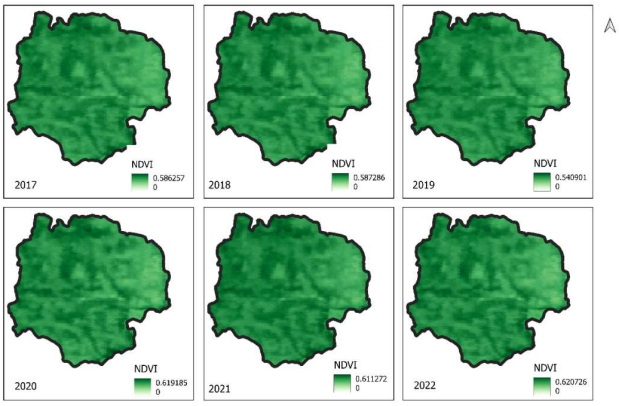

Fig. 4. NDVI map of the Dang district during year 2017 to 2022

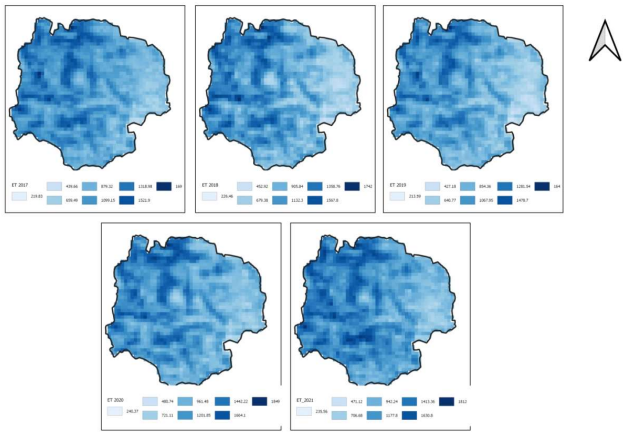

Fig. 6. ET_a map of the Dang district during year 2017 to 2021

Table 2. Surface water area of the Dang district

Year	Surface water area (km^2)				
	January	February	March	April	May
2017	9.50	7.20	4.00	2.11	0.42
2018	10.04	7.11	4.81	2.06	0.36
2019	8.05	5.19	3.11	2.11	0.49
2020	10.05	7.80	4.70	3.09	1.85
2021	10.22	7.80	4.63	2.34	1.17
2022	9.73	8.04	5.62	2.82	0.08

Table 3. Average annual climatic parameter for the Dang district

Year	Precipitation (mm)	Year	LST (°C)	NDVI	ETa (mm)
2016	1205	2017	35.62	0.457	1057.02
2017	1212	2018	35.58	0.459	1027.15
2018	941	2019	36.30	0.426	942.43
2019	1498	2020	35.15	0.482	1127.99
2020	1756	2021	34.59	0.495	1175.59
2021	1223	2022	34.15	0.487	-

year 2019.Further, higher precipitation in the previous year (2020) accumulates more surface water availability and thus increases NDVI and ETa, while following year LST will be lower during 2021indicate that LST had negative relationship to surface water availability, whereas rainfall, NDVI and Eta had positive relationship with surface water availability. This spatial and temporal information of surface water facilitate a valuable insight especially in the forest such as migration of wild animals, site suitability for develop nursery, planning of water conservation structure, *etc*. Rapid spatial and temporal surface-water assessment using remote sensing techniques opens up a lot of possibilities for managing, monitoring, and planning of forest water resources.

CONCLUSION

Monthly changes in surface water availability coupled with precipitation, LST, NDVI and ETa were reflected in this study. Lowest rainfall occurred in the year of 2018 showed higher LST in contrary NDVI and ETa observed lowest in the year 2019. Higher is the previous year precipitation (2020) accumulates more surface water availability and thus increases NDVI and ETa, while following year LST will be lower during 2021. Therefore, Remote sensing and GIS significantly contribute in rapid assessment of surface water availability in open-source platform like Google Earth Engine which reduces the cost and time for different decision-making process of forest and its conservation.

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Allelopathic Effect of Sesame Varieties on Germination and Seedling Growth of Cowpea and Okra

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***Abstract*:** A study was undertaken to examine the allelopathic effect of leachates prepared using different sesame varieties of India on germination and seedling growth of cowpea and okra seeds. The allelopathic potential of sesame varied with the varieties. The leachates of sesame varieties reduced the germination percentage of cowpea and okra by 5 to 62.5 % and 8.33 to 53.85 %, respectively, compared to control. Impairment of metabolic activities due to the application of leachates resulted in decreased root and shoot length of both the test crops. Compared to control, the leachates inhibited the seedling fresh weight by 23.02 to 55.77 % and 7.27 to 52.73 %, respectively in cowpea and okra. The sesame varieties, GT-10 and TMV-7 recorded the highest inhibitory effect on the germination parameters, seedling growth attributes, soluble protein content and ascorbic acid content of both the test crops. The presence of higher concentration of allelochemicals like phenolic acids, flavonoids, alkaloids etc. in the varieties might have attributed the inhibitory effect. Therefore, cowpea and okra might not be suitable for sequential cropping with sesame.

***Keywords*:** Allelochemicals, Germination, Inhibition, Leachate, Sesame

Allelopathy refers to the effect of plants on other plants in its vicinity or associated microflora/microfauna through the release of allelochemicals that intercede with the growth of plants (IAS 2018). Allelochemicals are secondary metabolites that possess defence against microbial and herbivore attack or competition from other plants (Kong et al 2019) and directly affect neighbouring plants by disrupting germination and seedling growth (Zhang et al 2020). The complex allelopathic inhibition involves interaction of different chemical classes, such as phenolic compounds, terpenoids, alkaloids and nitrogen containing compounds (Palaniswamy et al 2020). Allelopathic crops in the intercropping system, release allelochemicals into the environment *via* root exudation, volatilization, leaching or decay of crop debris. Allelopathy is considered as a chemical warfare amongst several plant species in which various biochemical and physiological processes like cell division and elongation, respiration, photosynthesis, enzyme activity, water relations, hormone levels, mineral availability and antioxidant system are affected (Zeng et al 2001). Sesame belong to Pedaliaceae family, encompasses a wide range of allelopathic properties and contains allelochemicals like phenols, saponins, flavonoids, tannins and alkaloids (Fasola and Ogunsola 2014). The alleochemicals present in sesame whole plant extracts *viz*., terpenes, hydrocarbons, fatty acids, phenolic acids and alkaloids delayed growth and germination of canola (Soleymani and Shahrajabian 2012). Allelopathic effects varied among different varieties of the same crop and study on the allelopathic effect of different sesame varieties on other crops are scanty. Sesame is usually raised in the summer rice fallows and followed by vegetables like cowpea and okra in Kerala. A study was conducted to envisage the effect of leachates from different sesame varieties on germination and seedling growth of cowpea and okra.

MATERIAL AND METHODS

Seeds of sesame varieties, Kayamkulam- 1, Thilathara, Thilarani, and Thilak, were procured from Onattukara Regional Agricultural Research Station (ORARS), Kerala, varieties, GT- 3, GT -5 and PKDS-8 from All India Coordinated Research Project (AICRP) on Sesame and Niger, Jabalpur, variety GT -10 from Agricultural Research Station (ARS), Amreli and varieties, TMV- 7, TMV -5 and VRI-1 from Regional Research Station (RRS), Vridhachalam. All the varieties were black seeded. The crop was raised at College of Agriculture, Vellayani from June to August 2022. The site was located at 8°30'N latitude, 76°54'E longitude and at an altitude of 29 m above mean sea level. Fresh plant samples were collected at active growth stage (30 DAS) for the conduct of experiment. The samples were thoroughly washed with water to remove the soil and dirt adhered to it. Allelopathic study was conducted using whole plant leachate of different sesame varieties.

Preparation of leachate: Sesame varieties were chopped

separately into small pieces of 2 cm length using a plant cutter. The leachates of 1:10 (w/v) concentration was prepared by soaking 100 g of each variety in 1000 mL distilled water for 72 h (Tomar et al 2015). The leachates were filtered using Whatman No.1 filter paper (pore size 11 µm) was used for treating cowpea and okra seeds.

Bioassay: Cowpea variety Vellayani Geethika and okra variety Salkeerthi were used as the test crops for bioassay. Ten seeds of each test crop were placed in the petri dish of diameter 9 cm, lined with filter paper**.** The filter paper was moistened with 5 mL of leachate prepared from eleven sesame varieties in alternate days. Petri dish moistened using distilled water was taken as control. The experiment was replicated 4 times and repeated twice for confirmation. The seeds of okra and cowpea were kept for germination, for a period of 21 days and 8 days, respectively (Agrawal 1994). Seeds with emerged radicle (2mm) were considered as germinated. Observations on the number of seeds germinated, seedling shoot and root length, seedling fresh and dry weight were recorded. The seedlings were dried in hot air oven at 65 ± 5°C to record the dry weight. From the above observations, germination percentage, seedling vigour index I and seedling vigour index II were computed.

1. Seedling vigor index I (SVI I) = Seedling length (cm) × Germination percentage
2. Seedling vigor index II (SVI II) = Seedling dry weight (g) × Germination percentage

The soluble protein content (mg/g) of cowpea and okra seedlings were estimated by Bradford, simple protein- dye binding bioassay using bovine serum albumin as standard. The ascorbic acid content of the test plants was volumetrically estimated by the method developed by Sadasivam and Manickam (2008) and expressed in mg/100g.

Statistical analysis: The statistical analysis was done using grapes Agri 1 software (Gopinath et al 2021).

RESULTS AND DISCUSSION

Germination parameters of cowpea and okra: The leachates prepared from different varieties had an inhibitory effect on germination parameters *viz*., germination percentage, SVI-I and SVI-II of both the test crops. Leachate prepared using variety GT-10 recorded the lowest germination percentage in cowpea (37.50 %) and was statistically comparable with TMV-5 (42.50 %). Sesame variety GT- 10 recorded the lowest SVI-I and SVI-II (111.00 and 4.26 respectively) and was statistically on par with TMV-5 (146.25 and 5.09 respectively). The SVI-I and SVI-II of cowpea seedlings treated with GT- 10 were 85.15 and 78.52 % lower than control (Table 1). The lowest germination percentage in okra was observed with the leachate prepared using TMV-5 (45.00 %) and was on par with GT-10 (50.00 %). The lowest SVI-I in okra was recorded by TMV-5 (222.75) which was statistically on par with GT-10. The SVI-I of okra seedlings treated with TMV-5 was 77.44% lower than control. However, the lowest SVI-II was in GT- 10 (0.69) which was statistically comparable with TMV-5. The SVI-II of okra seedlings treated with TMV-5 was 96.43 % lower than control. Oudhia and Tripathi (2000) observed that, sesame leaf extract (1:10 w/v) had significant inhibitory effect on germination and seedling vigour of rice. Duary (2002) documented the inhibitory effect of sesame leaf extract on

Table 1. Effect of leachates on germination of cowpea and okra

Varieties	Germination percentage		SVI I		SVI II	
	Cowpea	Okra	Cowpea	Okra	Cowpea	Okra
Kayamkulam-1	75.00	85.00	391.25	614.50	12.10	15.61
Thilathara	87.50	70.00	453.25	495.60	13.62	10.50
Thilarani	90.00	67.50	472.50	531.50	14.24	10.41
Thilak	67.50	77.50	342.00	571.50	12.89	10.86
GT-10	37.50	50.00	111.00	240.25	4.26	0.69
TMV-7	77.50	62.50	372.75	520.50	11.67	11.22
TMV-5	42.50	45.00	146.25	222.75	5.09	0.81
GT-3	50.00	57.50	178.00	413.75	6.46	10.09
GT-5	82.50	75.00	344.75	521.75	10.82	10.84
PKDS-8	87.50	82.50	521.25	729.25	15.75	14.85
VRI-1	95.00	90.00	567.25	781.00	15.96	16.94
Control	100.00	97.50	747.50	987.50	19.83	19.33
LSD (p=0.05)	8.736	11.128	54.211	92.174	1.593	1.854

seed germination, seedling growth and dry matter production of black gram and rice. Sesame contains 776 secondary metabolites, among which phenolic acids (18 %), lipids (16 %), flavonoids (14 %), organic acids (9 %) and amino acid derivatives (9 %) are dominant (Dossou et al 2021).

High level of phenolic compounds delay seed germination, enhances cell membrane permeability, lipid peroxidation and seed mortality (John 2012). The inhibition on germination of cowpea and okra seeds by application of leachates prepared from varieties GT-10 and TMV-5 might be due to the presence of higher concentration of secondary metabolites in the varieties. The phenolic acids in sesame leachate inhibit the activity of gibberellic acid by triggering the activity of abscisic acid, salicylic acid and jasmonic acid and thus inhibiting the seed germination (Kang et al 2015). Sesame leaves contains chemical compounds like epigallocatechin, 3-epibartogenic acid and kaempferol derivatives that hinder the activity of α- amylase, required for seed germination (Dat et al 2016). Bais et al (2003) observed that allelochemicals inhibit the germination parameters by triggering the production of reactive oxygen species (ROS) which cause a cascade of Ca^{2+} signaling that lead to genomic changes and lethal effects on the plant.

Seedling growth parameters of cowpea and okra: The shoot length of cowpea seedlings was significantly inhibited by GT-10 (1.20 cm) which was on par with GT-3 (1.43 cm). The lowest seedling root length was observed in GT- 10 (1.75 cm) which was comparable with TMV-5 (1.88 cm). The fresh weight and dry weight of seedlings were significantly decreased by the application of leachate prepared using variety GT-10, (0.23 g and 0.11 g respectively) which was on par withTMV-5 (0.25 and 0.12 g) (Table 2). Similar trend was observed in okra also. Leachate prepared using variety GT-10 (2.85 cm) recorded the lowest seedling shoot length which was on par with TMV-5. The root length of okra seedlings was significantly inhibited by GT- 10 (1.98 cm) which was statistically comparable with TMV-5. The fresh weight (0.26 g) and dry weight (0.01g) of okra seedlings were significantly decreased by the application of GT-10 leachate. It was statistically on par with TMV-5, for fresh weight and dry weight, respectively. Zhu et al (2005) opined that allelopathic response of plants depends on the type and concentration of allelochemicals. The leachates of TMV-5 and GT-10 might have contained higher concentration of allelochemicals, which lead to higher level of inhibition. Impaired metabolic activities in response to allelochemicals might have decreased shoot length and root length of both the test crops. Shah et al (2016) revealed that sesame had an inhibitory effect on the growth and yield attributes of green gram grown in replacement series. Premature lignification caused by allelochemicals results in arrested growth of plants (Santosh et al 2004). The phenolic allelochemicals inhibits cell division, alters the cell structure and could impede the absorption of water and nutrients leading to production of dwarf plants (John 2012, Scavo et al 2018).

Ascorbic acid and soluble protein content of cowpea and okra: The soluble protein content and ascorbic acid content of cowpea and okra varied significantly in response to application of different leachates (Fig. 1 and 2). The soluble protein content of cowpea seedlings was significantly decreased by the application of GT-10 (0.29 mg/g) which was on par with TMV-5. While, GT-10 (0.22 mg/g) recorded the

Table 2. Effect of leachates on seedling growth of cowpea and okra

Varieties	Seedling shoot length (cm)		Seedling root length (cm)		Seedling fresh weight (g)		Seedling dry weight (g)	
	Cowpea	Okra	Cowpea	Okra	Cowpea	Okra	Cowpea	Okra
Kayamkulam-1	2.25	4.18	2.98	3.05	0.32	0.51	0.16	0.18
Thilathara	2.48	3.85	2.70	3.23	0.35	0.35	0.16	0.15
Thilarani	2.33	5.10	2.93	2.78	0.34	0.34	0.16	0.15
Thilak	2.25	4.43	2.83	2.95	0.39	0.36	0.19	0.14
GT-10	1.20	2.85	1.75	1.98	0.23	0.26	0.11	0.01
TMV-7	2.35	5.38	2.45	2.95	0.40	0.51	0.15	0.18
TMV-5	1.55	2.93	1.88	2.03	0.25	0.28	0.12	0.02
-3	1.43	4.23	2.15	3.00	0.29	0.47	0.13	0.18
GT-5	1.95	4.18	2.23	2.78	0.29	0.36	0.13	0.15
PKDS-8	2.88	5.55	3.08	3.28	0.39	0.46	0.18	0.18
VRI-1	2.78	5.63	3.20	3.05	0.36	0.45	0.17	0.19
Control	3.35	6.30	4.13	3.83	0.52	0.55	0.20	0.20
LSD (p=0.05)	0.251	0.340	0.306	0.327	0.032	0.032	0.009	0.006

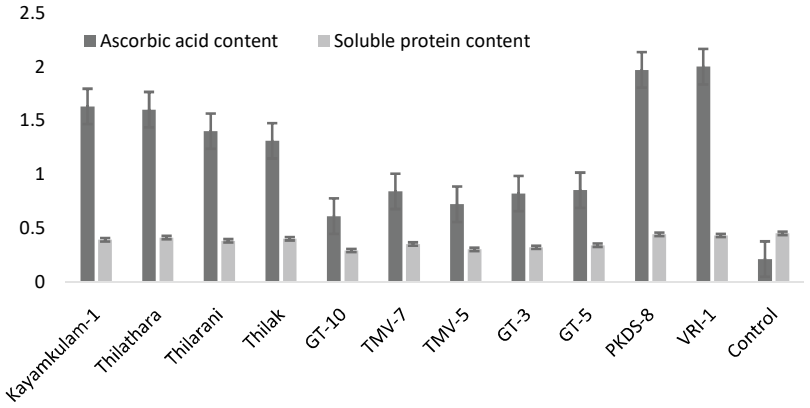

Fig. 1. Effect of sesame leachate on ascorbic acid content (mg/100g) and soluble protein content (mg/g) of cowpea

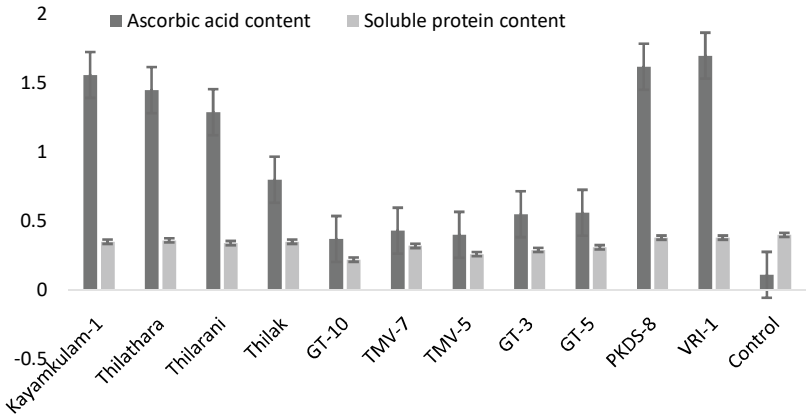

Fig. 2. Effect of sesame leachate on ascorbic acid content (mg/100g) and soluble protein content (mg/g) of okra

lowest soluble protein content in okra seedlings. The reduction in soluble protein content of both the test crops were attributed to the oxidative damage imparted with the application of leachates. The seedlings of the test crops with the lowest soluble protein content recorded the lowest growth parameters. Allelochemicals like phenolics could inhibit the amino acid transport, protein synthesis and subsequent growth of plants (He and Lin 2001). The ascorbic acid content was significantly lower for cowpea seedlings treated with GT-10 (0.61 mg/100g), which was on par with TMV-5. Similar trend was observed in okra also. The lowest ascorbic acid content in okra was recorded by the application of GT-10 (0.37 mg/100g) which was statistically on par with TMV-5 and TMV -7. The non -enzymatic anti-oxidant, ascorbic acid was produced as a defensive mechanism against the phytotoxic stress induced by the allelochemicals present in the leachates. The ascorbic acid content was remarkably reduced by the application leachate prepared from varieties GT- 10 and TMV-5. The decrease in the antioxidant content might have impeded the germination and seedling growth.

CONCLUSION

The inhibitory effect of leachates from different sesame varieties on germination and growth of cowpea and okra revealed that leachates prepared using varieties GT-10 and TMV-5 significantly inhibited germination and growth of both the test crops. The allelopathic compounds in sesame leachates like phenolic acids, flavonoids, alkaloids and nitrogen compounds might have attributed to the inhibitory response. The study indicate that cowpea and okra is not suitable for simultaneous cropping or sequential cropping with sesame.

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Response of Weed Population Dynamics and Communities on Yield: A Case Study Using *Trigonella foenum-graecum* L.

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***Abstract*:** Field experiments were conducted for two successive years at Agronomy Research farm, CCS Haryana Agricultural University, Haryana during 2018-19 and 2019-20 to evaluate the efficacy of herbicide-based IWM strategies and to study the response of weed population dynamics and communities on fenugreek yield. Total weed density was lower in the first year as compared to second year *i.e.* 80 and 88 weeds m^{-2}, respectively. Dicotyledon/broad-leaved weeds (84.3 and 88.1% relative density) were more prevalent than monocotyledon grassy/sedge weeds, with relative densities of 13.7 and 11.9%, respectively during both years. Lower dry weight of weeds was recorded with two hoeing employed at 30 and 60 DAS which was statistically at par with PRE application of pendimethalin + imazethapyr (RM) at 1500 g ha^{-1} + one hoeing at 3-4 leaf stage. Among the IWM practices evaluated in fenugreek, pendimethalin + imazethapyr at 1500 g ha^{-1}as pre-emergence and then one spot hand weeding at 30–35 days after sowing was effective in controlling weeds which was 87.0 and 83.7% higher, respectively in first and second year than that in unweeded control. The use of imidazolinones in combination with pendimethalin (RM) improved its efficacy in controlling the predominant weeds. We concluded that a management programme based on the combination of herbicides applied at early stages with one hoeing at 3-4 leaf stage will be effective to control the future infestations in legume crops.As a result, coupling pendimethalin and imazethapyr may result in improved weed control as well as increased fenugreek productivity and profitability.

***Keywords*:** Fenugreek, *Trigonella foenum-graecum,* Integrated weed management, Weed dynamics, Weed suppression

Legume is considered as the most valuable plant because of its high grain protein content and potential to fix biological nitrogen. Fenugreek (*Trigonella foenum-graecum* L.), is a multiuse seed spice crop of arid and semi-arid regions of India. India is among the largest producers in the world, occupying 169 thousand ha area with an annual output of 252 thousand MT and average productivity of 1.7 MT ha^{-1} (Anonymous 2021). Improved agronomic approaches, especially effective weed management, have the potential to raise fenugreek yield in Haryana. Weed suppression is one of the most significant factors of a crop's yield advantage, and the influence on production is determined by the interaction of the crop and weed flora. Weed removal is one of the most important ways to circumvent crop losses. In India, the strategy for weed management in legume has not changed except for the introduction of novel combinations or formulations of currently available active ingredients. One alternative is the use of acetolactate synthase (ALS)-inhibitor herbicides. In many crops, this method of action consists of five chemical groups with varied efficacy against dicotyledonous and monocotyledonous weeds. Selectivity is that property of herbicides which help them to eradicate the weeds without affecting the crop plant in the field (Bajwa 2016). Herbicide applications that have a low selectivity trigger phytotoxicity in the crop. In northwestern India, weed poses a severe threat to legumes yield and it must be countered using integrated weed management strategies that include herbicide combinations, crop and herbicide rotations, cultural and mechanical methods, and more. Weed populations resistant to multiple site-of-action (SOA) herbicides are becoming more common and pervasive in many agro zones with high-input intensive cropping (Beckie et al 2020, Heap 2020). In legume crops, post herbicides are used less extensively. For this context, we discuss some feasible weed management options. To suppress economically damaging weeds, are usually treated just before or at seeding. Weeds have a negative impact on crop development and productivity because they compete with crops for limited resources like light, water, and nutrients (Swanton et al 2015). The extent of crop production losses is determined by the intensity and length of the crop-weed competition. Herbicides are the most widely used weed management tools in agriculture, with a global herbicide market worth an estimated $27 billion per year (Kraehmer 2012). As a result of this over-reliance on same-site-of-action herbicides in cropping systems, herbicide-resistant (HR) weed populations have grown substantially over the world (Heap 2016). Insurgent reports on HR weed numbers represent a severe danger to the US cropping systems' long-term resilience. Furthermore, given the absence of any new site-of-action herbicide discovery in the last two decades, the expense of managing HR weeds

has risen, exacerbating the situation (Duke 2012). In herbicide-restricted environment, effectively and profitably managing troublesome weeds in key agronomic field crops will be difficult, but it might be viewed as a chance for much more adoption of ecologically based weed management approaches, strategies, and systems. The success of integrated weed management techniques depends on the reliability of control operations in both time and space. While spatial precision has gotten a lot of attention, time accuracy has gotten the short end of the stick. Developing integrated weed management (IWM) solutions has long been a goal of agricultural research, particularly for economic and ecological sustainability (Clements et al 1994, Bajwa 2014). The IWM system necessitates a thorough understanding of weed biology and their significance in the agro-ecosystem, as well as the development of criteria for determining when to manage these weeds. These criteria must encompass agronomic and economic considerations (Wilkerson et al 2002). In addition, IWM must include a number of complementary measures aimed at suppressing or eliminating weed establishment throughout the year in order to satisfy production goals, whether they be economic or ecological. The goal of weed control, on the other hand, is to successfully eliminate unwanted plants by the use of mechanical or chemical methods. Achieving IWM needs not only a variety of tools, but also quick response. It is not rare for weed control techniques to be deployed too late for effective control of individuals, resulting in escapes, an augmented soil seed bank, and the evolution of herbicide resistance (Neve et al 2010). Understanding how crop management practises affect weed emergence, survival, and seed production is critical for optimising long-term weed management strategies. Preplant weed control, on the other hand, will be less effective if a weed species has a protracted emergence pattern or emerges in numerous flushes and becomes tall quickly. Herbicides are primarily used in the field to reduce weed competition with crops that emerge at the same time. Imazethapyr can be used as pre-plant incorporated (PPI), pre, and post treatments to control a wide range of grass and broad-leaved. Therefore, the purpose of this study is to quantify the impact of different management tools on dominant weed flora in fenugreek crop. These findings may lead to more proactive, long-term approaches for effective weed management, thus, reducing producer reliance on herbicides. As a result, using non-chemical weed management methods in weed management programmes is critical for long-term crop performance. Herbicide resistance is evolving, and chemical alternatives are limited, thus a rational way of tackling problematic weeds is necessary.

MATERIAL AND METHODS

Description of field sites and experimental design: Against the predominant weeds in fenugreek, to assess the bio-efficacy of pre and post herbicides both separately and in combination, two field experiments were conducted on the Research farm of CCS Haryana Agricultural University, Hisar, Haryana, India (29° 10´N, 75° 46´E) during the winter seasons of 2018-19 and 2019-20. The rainfall received in the 2018 and 2019 cropping seasons was 28.6 and 32.4 mm, respectively. The experimental design was randomized complete block with three replications. The soil of the field was sandy loam in texture, low in nitrogen (181 kg ha^{-1}), medium in phosphorus (17 kg ha^{-1}) and high in potassium (285 kg ha^{-1}). With the help of a tractor-drawn cultivator, the field was ploughed twice to crush the clods. The field was cleared of previous crop leftovers. Ploughing was accomplished again by cross harrowing, followed by cultivator twice, and planking to achieve a fine tilth of the soil. Fields were fertilised with 20 and 40 kg ha^{-1} of nitrogen and phosphorous, respectively through DAP before sowing in each year. Each plot size was 6.0m × 6.0m. The fenugreek variety HM-51 was sown on 22 November 2018 and 19 November 2019 during 2018-19 and 2019-20, respectively. At 20 cm row spacing, the seeding rate was 25 kg per hectare. With a knapsack sprayer equipped with a flat fan nozzle and a 500 L ha^{-1} spray volume, preemergent herbicides were sprayed right away after sowing in moist soil, and additional post-emergent herbicides were applied at 46 DAS. The crop was managed according to the standard agronomic practices of the state university. Most abundant species (>5% of the relative density) found in the experimental area during 2018 and 2019 were (Table 1). *Melilotus indica* (7.7 and 8.6%), *Anagallis arvensis* (23.5 and 22.5%), *Rumex dentatus* (14.0 and 14.0%), *Lathyrus aphaca* (11.8 and 11.3%), *Medicago denticulata* (21.6 and 20.6%), *Phalaris minor* (13.7 and 14.4%) and *Coronopus didymus* (7.7 and 8.6%) at 45 DAS.

Treatments: Treatments in the study were T1: PRE imazethapyr at 80 g ha^{-1}, T2: PRE imazethapyr at 80 g ha^{-1} + one hoeing, T3: POE imazethapyr at 80 g ha^{-1}, T4: PRE imazethapyr + imazamox (RM) at 70 g ha^{-1}, T5: POE imazethapyr + imazamox (RM) at 70 g ha^{-1}, T6: PRE imazethapyr + imazamox (RM) at 70 g ha^{-1}, T7: PRE pendimethalin at 1000 g ha^{-1}, T8: PRE pendimethalin at 1000 g ha^{-1}+ one hoeing, T9: PRE pendimethalin + imazethapyr (RM) at 1000 g ha^{-1}, T10: PRE pendimethalin + imazethapyr (RM) at 1250 g ha^{-1}, T11: PRE pendimethalin at 1500 g ha^{-1}, T12: PRE pendimethalin + imazethapyr (RM) at 1500 g ha^{-1} + one hoeing, T13: weed-free along with T14: weedy check and T15: two hoeing at 30 and 60 DAS. Treatments 3 and 5

follow the post-emergence timing (3-4 leaf stage/46 DAS) of the weed control strategy, treatments 2, 6, 8 and 12 exemplify weed control strategies with PRE application of herbicides along with one hand hoeing at 3-4 leaf stage. The weed-free control plots were kept weed-free by hand-weeding as and when required, and weeds were not removed in weedy check plots.

Weed sampling: Observations on weed density from two random spots was recorded at 75 DAS by placing a quadrate of size 0.5 m × 0.5 m. The weed biomass was recorded at 75 DAS. Dry weight of weeds was recorded after drying the weeds in the sun and later in an oven at 60ºC up to 72 hr. till a constant weight was attained. Then, prior to conducting a statistical analysis, the dried weed sample weight was measured in units of g m^{-2}. The effectiveness of weed management was calculated as a percent decrease in total weed biomass under various treatments compared to weedy check at 75 DAS. On March 21, 2019 and 25, 2020, respectively, the crop was harvested when it reached complete physiological maturity. An area of 0.2 m on each side of the plot and one border row on both sides of the experimental plots were harvested first, thereafter the net area separately. Grain yield was determined at a moisture content of 14% after threshing with a plot thresher, followed by cleaning. The recorded data was converted into kg ha^{-1}. In order to calculate the weed index, crop production loss was added up throughout treatments in comparison to the weed-free plot.

Statistical analysis: Before statistical analysis, to increase the homogeneity of the variance, weed data was subjected to square root transformation (√X+1). Utilizing R statistical software version 0.1.0, all data were examined. The estimated regression equation has been constructed for both years and was used to study the relationship between seed yield and major weed densities using a linear bivariate regression analysis. In order to analyse the joint or combined effect of factors on grain production, various correlation studies were conducted on the relationship between wheat grain yield and total weed density, weed dry weight, total N, P, and K absorption.

RESULTS AND DISCUSSION

Weed interference: There were two monocotyledon grasses and six dicotyledon weeds in the experimental pea field (Table 1). In comparison to the second year, the total weed density was lower in the first year (80 and 88 weeds m^{-2} respectively). Dicotyledon/broad-leaved weeds (84.3 and 88.1 percent relative density) were more prevalent in the first and second year than monocotyledon grassy/sedge weeds, which had relative densities of 13.7 and 11.9 percent, respectively. Weed species that showed up in the experimental field were gathered, identified, and listed in Table 1. *Anagallis arvensis* was the most prevalent weed *(23.5* and *22.5 percent relative density)* followed by *Medicago denticulata* , *Rumex dentatus* , *Lathyrus aphaca* and *Phalaris minor* during 2019 and 2020, respectively.

Regression studies between weed density and yield in fenugreek: The results of the regression analysis showed unequivocally that the fenugreek seed yield was inversely related to the total density of weeds (Fig. 3). Strong correlation was observed between weed density and yield in case of *Coronopus didymus* and *Melilotus indica* (Table 2). The robustness of the relationship between seed yield and weed density under various weed control methods was confirmed by the fitted regression model's goodness of fit for the years 2018–19 and 2019–20 (R^2 = 0.93) and (R^2 = 0.92).

Crop growth that is morphological is the outcome of interactions between a plant's environment and its genetic characters. At all the stages of crop growth, *Anagallis arvensis* and *Medicago denticulata* dominated the weed flora. The regression model for seed yield on density of predominant weeds *viz. Melilotus indica* (R^2 = 0.92, 0.93),

Table 1. Weed flora of the experimental field and their relative density

Scientific name	Common name	Family	Habit and characteristics	Relative weed density in weedy check at 45 DAS (%)	
				2018-19	2019-20
Melilotus indica L.	Sweet clover	Leguminosae	Annual broad- leaved herb	7.7	8.6
Anagallis arvensis L.	Pimpernel	Primulaceae	Annual broad- leaved herb	23.5	22.5
Medicago deniculata L.	Bur clover	Leguminosae	Annual broad- leaved herb	21.6	20.6
Rumex dentatus L.	Golden dock	Polygonaceae	Annual broad- leaved herb	14.0	14.0
Lathyrus aphaca L.	Yellow pea	Leguminosae	Annual broad- leaved herb	11.8	11.3
Phalaris minor L.	Canary grass	Poaceae	Annual grass herb	13.7	14.4
Coronopus didymus L.	Swinecress	Brassicaceae	Annual broad- leaved herb	7.7	8.6

Anagallis arvensis (R^2=0.86, 0.85), *Coronopus didimus* (R^2=0.93, 0.94), *Rumex dentatus* (R^2=0.82, 0.73) and *Medicago denticulata* (R^2 = 0.86, 0.87) demonstrated significant dependence. Population dynamics (number m^{-2}) was significantly influenced by different weed management practices. The degree of goodness of the fitted regression model for seed yield on total weed density during both the years (R^2 = 0.91, 0.87, respectively) showed strong relation of weed densities on seed yield. Effective weed management have developed suitable environmental conditions for water and nutrient absorption in fenugreek crop. Thus, enabled availability of nutrients, water, light and space to the crop which resulted into increased plant height. The results of this study are validated by Kamboj et al (2005) and Chovatia et al (2010).

Correlation of total weed density, weed dry weight, total N, P and K uptake with yield: The correlation matrix (Table 3) demonstrated the linear relationship between the variables, highlighting the significant influence of each parameter, including total weed dry weight and density, total N uptake, total P uptake, and total K uptake on fenugreek seed yield under various weed control methods. The matrix showed that there was a strong negative association between fenugreek seed yield and total weed density (r = -0.95) and dry weight (r = -0.93) of weeds, but a strong positive correlation between fenugreek seed yield and total N, P, and K uptake. The uptake of total N (r = -0.94 and -0.95), P (r = -0.93 and -0.96), and K (r = -0.94 and -0.96) was negatively correlated with the total density and dry weight of weeds. The negative relationship between weed density and yield was observed under all the weed control treatments during 2018-19 (Fig. 1a) and 2019-20 (Fig. 1b).

Impact of weed management on weeds in fenugreek: Through this experiment, the types of weed species, including susceptibility/tolerance and growth stages, as well as the chemical make-up and timing of herbicide applications, all had an impact on weed control. Temperature and rainfall have also had an impact on the effectiveness of herbicides throughout time. Pendimethalin and imazethapyr are broad-spectrum herbicides that are selective to pea and belong to two classes of herbicides with distinct mechanisms of action (Shalini and Singh 2014, Kukharchik et al 2013). Pendimethalin + imazethapyr (RM) at 1500 g ha^{-1} applied as pre-emergence, effectively controlled the dominant weed species in fenugreek (Singh et al 2016). All the weed species reported in this study were effectively managed by ready-mix herbicide formulations *viz.* imazethapyr + imazamox and pendimethalin + imazethapyr as compared to application of pendimethalin as PRE and imazethapyr as PRE and POE (Yadav et al 2015). Pendimethalin's ability to inhibit the growth of emerging weeds' roots and shoots is responsible for higher weed control effectiveness and percent weed control (Appleby and Valverde 1988; Holt et al 1993; Gilliam et al 1993) and imazethapyr's longer half-life, which ranges from 78 to 270 days, is responsible for the higher persistence of imazethapyr and as a result better control at later stages (Goetz et al 1990). The variation in weed count, their dry matter and weed control efficiency might be due to

Table 2. Regression relationship of grain yield with major weed densities (independent variables)

Independent variable	2018-19		2019-20	
Weed density	Estimated regression line	Adjusted R^2 value	Estimated regression line	Adjusted R^2 value
Melilotus indica	y = -0.0065x + 14.678	0.9244	y = -0.0075x + 15.36	0.9297
Anagallis arvensis	y = -0.013x + 31.725	0.8581	y = -0.0138x + 31.155	0.8491
Coronopus	y = -0.0049x + 10.884	0.9295	y = -0.0068x + 13.428	0.9452
Rumex dentatus	y = -0.0072x + 18.391	0.8243	y = -0.0082x + 19.966	0.7318
Medicago denticulata	y = -0.0136x + 31.932	0.8629	y = -0.0144x + 31.452	0.8755

Table 3. Correlation coefficient (n = 60) with exact probability level of significance

Pearson correlation coefficients	Seed yield	TWD	WDW	TNU	TPU	TKU
Seed yield	1	-0.951**	-0.933**	0.992**	0.992**	0.990**
Total Weed density (TWD)		1	0.869**	-0.940**	-0.932**	-0.944**
Total weed dry weight (WDW)			1	-0.955**	-0.958**	-0.962**
Total N uptake (TNU)				1	0.990**	0.997**
Total P uptake (TPU)					1	0.989**
Total K uptake (TKU)						1

differences in the effectiveness of herbicides used against different weeds in the field (Meena et al 2018). Lower dry weight of weeds was recorded with two hoeing employed at 30 and 60 DAS (Fig. 2) which was statistically at par with PRE application of pendimethalin + imazethapyr (RM) at 1500 g ha^{-1} + one hoeing at 3-4 leaf stage (Gupta et al 2017). Due to the pre-emergence treatment of various herbicides, a significant decrease in weed density and dry weight was seen, which produced a favourable environment for the crop. The weeds that germinate either before or along the crop offer higher competition as compared to later germinating ones. Weeds accumulates dry matter faster as compared to crop plants. The prolonged time of weed control and weed spectrum in herbicide mixtures lead to better weed control. The weaker second and third cohorts of weeds were managed by imazethapyr due to its increased persistence and one hand hoeing at 3-4 leaf stage. Pre pendimethalin eliminated the initial cohorts of weeds. The principal weed cohorts in PoE alone treatments get an early start due to the initial slow growth of the crop and are subsequently not efficiently eliminated by PoE herbicides, in alone pretreatments the later appearing weeds continued to contend with the crop. Most effective herbicide treatment *i.e.* pre pendimethalin + imazethapyr (RM) at 1500 g ha^{-1} + one hoeing at 3-4 leaf stage recorded highest seed yield. This may be attributed to a decrease in weed density and dry weight caused by the sequential application of herbicides that killed the majority of the weed cohorts. This helped the

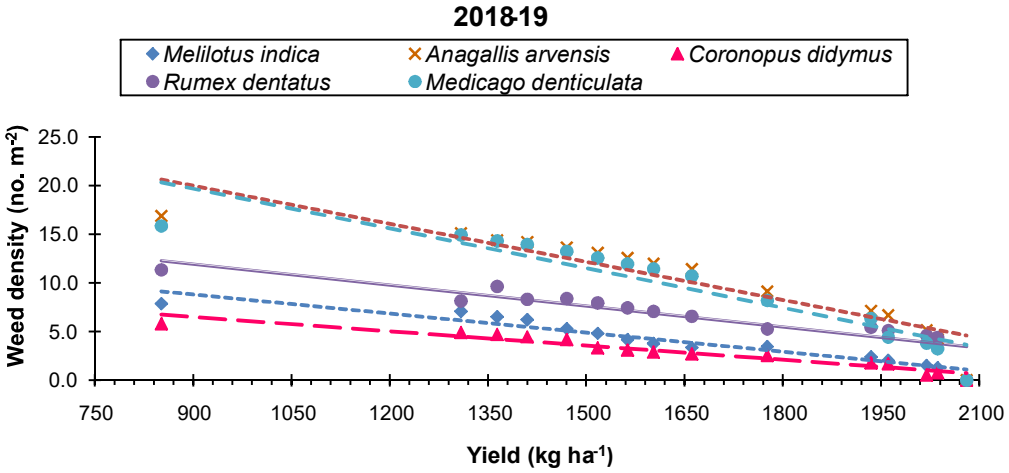

Fig. 1a. Relationship between weed density (no. m^{-2}) and yield in different weed control treatments during the year 2018-19

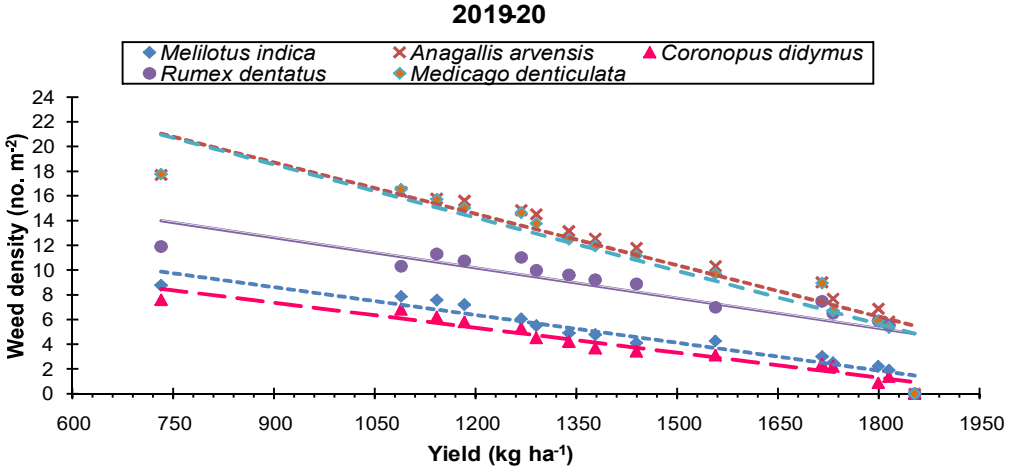

Fig. 1b. Relationship between weed density (no. m^{-2}) and yield in different weed control treatments during the year 2019-20

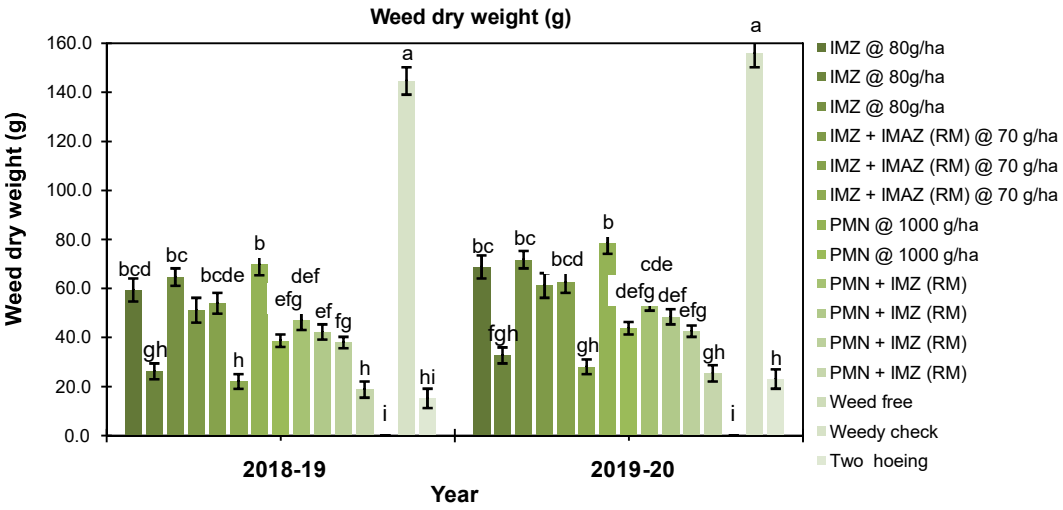

Fig. 2. Effect of weed control treatments on weed dry weight in fenugreek during both the years

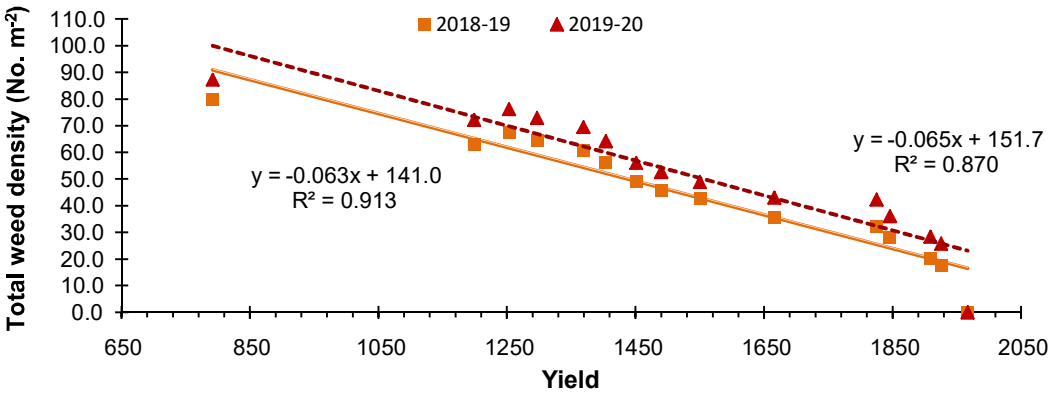

Fig. 3. Effect of total weed density on seed yield in fenugreek during both the years

crop utilise nutrients, moisture, light, and space more effectively, resulting in higher dry weight, more effective tillers, more grains per spike, and higher test weight, all of which increased grain yield.

CONCLUSION

The findings of this study will assist reduce reliance on a single site-of-action herbicide, lowering the selection pressure for herbicide-resistant weed populations in a crop production systems. Integrated weed management strategies are a beneficial weed management tool for inclusion in Indian agricultural production systems in the light of changing weed flora in response to management practices. Herbicides should be used with prudence, avoiding higher-than-recommended doses and employing a variety of control methods such as mechanical, manual, and cultural control. Herbicide alternatives for the treatment of innumerable weed flora issues in legumes are suggested by the findings of this study. The ready mix formulation *viz.* pendimethalin + imazethapyr at 1500 g ha^{-1} in combination with one hoeing applied at 3-4 leaf stage can be a profitable alternative to the single site-of-action herbicides in fenugreek. Incorporating integrated techniques into a weed management programme as a routine weed control approach will surely result in more effective control and a reduction in herbicide resistance evolution. These herbicide mixtures look to be a realistic alternative till then. This approach can be used in similar agro-ecologies in the tropics and subtropics as well as in India's North-western Indo-Gangetic Plains.

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AUTHOR CONTRIBUTIONS

Conceptualization, Isha Ahlawat and Todarmal; Formal analysis, Todarmal; Methodology, Sumit Bhardwaj and Anjali

Rana; Supervision, Todarmal; Writing-review & editing, Anjali Rana and Abhishek. All authors have read and agreed to the published version of the manuscript.

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Breeding Potential of Sweet Pepper Genotypes Involving Different Fruit Colours and Shapes Using Multivariate Analysis

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***Abstract*:** The study was undertaken to characterize and determine the genetic divergence of 21 sweet peppers genotypes having different fruit colours and shapes. High Shanon-Wiener diversity index with an overall mean of 70.71 % confirmed the existence of diversity among the studied genotypes. Fruits started developing colours in 19 to 68 days after anthesis depending on the genotype. High heritability coupled with high genetic advance as per cent of mean was observed for all the traits except days to first harvest, revealing additive genetic control of most traits. Number of fruits/plant and fruit weight were identified as important selection indices for yield improvement. Sweet pepper genotypes could be grouped into 5 clusters which do not represent places of origin indicating genotypes in a cluster were geographically diverse; genotypes obtained from the same region were genetically different. The principal components, β-carotene content, number of fruits/plant, lycopene content of fruit and average fruit weight, had eigen values >1 and together accounted for 100% of total variation.Based on multivariate analysis and average performance, genotypes 'C/4' (Red Group 42A, blocky), '8/4' (Orange Red Group 34A, elongate), 'Arya' (Red Group 45A, blocky), 'Baby Bell' (Red Group 42A, blocky), 'BC CAP Purple' (Purple Group N77A, blocky), 'BC CAP Yellow' (Yellow Orange Group 17A, blocky) and 'BC CAP White' (Green white Group 157 C, blocky) were identified as good donors and could be utilized in future breeding.

***Keywords*:** *Capsicum annuum* var. *grossum*, Characterization, Genetic diversity, Colour pigments

Sweet pepper (*Capsicum annuum* var. *grossum* Sendt.) is one of the highly remunerative vegetables cultivated widely throughout temperate and sub-tropical Europe, USA, Africa, India, East Asia, and China (Bose et al 2021). The crop is appreciated worldwide for their flavor, aroma, color and are a rich source of capsaicinoids, carotenoids (some of them with provitamin A activity), flavonoids, ascorbic acid (vitamin C), and tocopherols (vitamin E) (Wahyuni et al 2011). Sweet pepper fruits are available in different shapes (elongate, almost round, triangular, campanulate and blocky) and colours (red, yellow, green, white, purple and orange) which decide the market value of the produce. The choice of fruit colour varies region to region. Based on fruit shape and size, more than 20 market types of sweet peppers are known. Sweet pepper fruit undergoes a distinct phase of colour change during its development. Different genotypes carry different genes for the expression of various fruit colours. Tian et al. (2015) named four key genes phytoene synthase (*Psy*), lycopene-β-cyclase (*Lcyb*), β-carotene hydroxylase (*Crtz*), and capsanthin/capsorubin synthase (*Ccs*) in the capsanthin biosynthetic pathway of pepper cultivars with red, yellow, and orange fruits. Another gene Anthocyanin (*A*) the incompletely dominant gene for anthocyanin colour in immature pepper fruit is also suggested by Lippert et al (1965). Transfer of important genes could be possible through hybridization. Lack of study on the development of different fruit colours hinders to identify the most appropriate stage of harvesting when the fruit show maximum attractiveness. Therefore, knowledge about different colour development of sweet pepper fruit is necessary for the breeders as well as the farmers. The breeding programmes so far carried out in this economically important crop have made little use of different coloured genotypes.

In recent past sweet pepper has attained an important status of "high value vegetable crop" in India due to its high nutritional value and export potential. Cultivation of sweet pepper in the cost effective naturally ventilated polyhouses has proved to be a very remunerative venture to the greenhouse growers as they are fetching maximum returns in the markets. A few old varieties are still recommended or available for commercial cultivation under polyhouse, which becomes poor yielder and vulnerable to insect-pest and

diseases. There is a need for genetic restructuring of the sweet pepper germplasm for increasing the productivity under low cost polyhouse considering the preference of the consumers. Presence of sufficient variability in basic genetic material of any crop is a pre requisite for effective selection and improvement of superior genotypes (Jogi et al 2015). Assessment of genetic variability in the available germplasm through parameters of variability helps to identify the potential genotypes for their use either directly as varieties or as parents in future crop improvement programmes. The study on genetic variability also generates valuable information pertaining to the type of gene action involved in the manifestation of different horticultural traits. Knowledge of inter-character relationship is equally important for indirect improvement of characters that are difficult to quantify especially those which exhibit low heritability. The complexity of character relationships among themselves and with fruit yield becomes evident from the discussion alone did not provide a comprehensive picture of relative importance of direct and indirect influences of each character to fruit yield, as these traits were the resultant product of combined effects of various factors complementing or counteracting. Therefore, information about direct and indirect relationship among any characters would help more realistic interpretation regarding influence of a character on a particular trait. The basic step for crop improvement relies on characterization and identification of existing germplasm. It is generally agreed that genetically diverse parents will show the maximum heterosis and offer the maximum chance of isolating transgressive segregates. This serves the purpose of identifying probable parents for obtaining the best recombinants from the population. Assessment of genetic diversity is important for selecting breeding strategies. Quantification of genetic divergence through biometrical procedures has made it possible to assess the variability pattern of specific characters in whole germplasm and to choose genetically diverse parents for successful hybridization. The present study aimed to identify important selection indices, to assess the genetic divergence of different sweet pepper genotypes having different fruit shapes and colours based on quantitative traits for identification of parents in hybridization programme.

MATERIAL AND METHODS

Experiments of the present investigation were carried out at Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani, Nadia, West Bengal, India. Twenty-one advanced breeding lines of sweet pepper collected from MIDH Project, BCKV, West Bengal and ICAR-IIVR, Varanasi, constituted the plant materials for this study. The genotypes were grown under low cost polyhouse (bamboo structured covered with 250µ UV stabilized cladding material with sides open) in randomized complete block design with three replications. Seed beds were prepared in a sandy loam soil and were 15 cm tall and 1.0 m wide. Well rotten cow-dung manure at 4 kg/m^2 was mixed into the beds. Beds were drenched with chlorothalonil @ 0.2 % + carbendazim @ 0.1 % to avoid damping off disease. Seeds, treated with thiram (3.0 g/kg of seed), were sown during the 1st week of October, 2019 at a shallow depth at 5 cm apart and covered with finely sieved well rotten leaf mould which acts as soil improver and to prevent the soil drying out. After sowing, beds were covered with straw until germination which normally takes five to seven days and hand watered regularly up to last week of October, 2019. Seedlings were hardened by with holding water 4 days before transplanting. The soil under polyhouse was prepared by hand tractor thoroughly to get a fine tilth before transplanting of the seedlings. Well rotten FYM @ 15 tons/ha was applied in the soil during the final land preparation. Thirty day old seedlings were transplanted in separate beds measuring 1.0 m × 4.0 m at 50 cm × 50 cm spacing during 1st week of November, 2019 under polyhouse in the afternoon hours. A fertilizer dose of 150 kg N, 75 kg P_2O_5 and 75 kg K_2O/ha was applied to the crop. Foliar sprays of micronutrient mixtures containing Zn, B and Mo were applied time to time. All the cultural practices scheduled for its cultivation were followed in time as per Bose et al (2021).

Observations were recorded from ten randomly selected plants from each genotype and the average was worked out for statistical computation. Ten fruits per genotype per replication were taken for recording different fruit characters. The fruits were cut into two halves to record pericarp thickness (mm) and locules per fruit. Qualitative traits like growth habit (Prostrate, Indeterminate, erect), leaf shape (Deltoid, Ovate, Lanceolate), flower position (Pendent, Intermediate, Erect), corolla colour (white, light yellow, yellow, yellow green, white with purple base, white with purple margin, purple with white base, purple), male sterility (absent, present), fruit shape (elongate, almost round, triangular, campanulate, blocky), and fruit colour at marketable maturity [(Royal Horticultural Society Colour Chart (RHCC)] were taken as per the minimal descriptors of NBPGR, New Delhi. Quantitative traits like plant height (cm), days to first flowering, days to 50% flowering, days to first harvest, number of primary branches/plant, fruit length (cm), fruit diameter (cm), shape index, fruit diameter, pericarp thickness (mm) of fruit, number of locules/fruit, number of seeds per fruit, number of fruits/plants, average fruit weight (g), fruit yield/ plant (kg) were taken. The cut fruits were used to make replication-wise composite sample to estimate fruit

quality characters,TSS content of fruit (^{0} brix) determined by hand Refractometer, Vitamin-C content of fruit (mg/100 g), Lycopene content of fruit (mg/100 g) and β-carotene content of fruit (mg/100 g) as per Sadasivam and Manickam (1996).

The data were subjected to the analysis of variance for randomized block design using Windostat software (ver.8.0, Indostat Services, Hyderabad, India). Frequency distribution was calculated from a set of morphological qualitative data from all the available variations in sweet pepper descriptor showing the number of occurrences (frequency) at each value or range of values. The frequency distributions were used to calculate the Shannon-Wiener diversity index (H') for each character (Hennink and Zeven, 1991). The index is defined as:

$$H' = -\sum_{i=1}^{s} (pi \ln Pi)$$

Where H'= diversity index; S = Total number of descriptors in the i^{-th} descriptor; Pi = fraction of individuals belonging to the i^{-th} descriptor state (number of observations/descriptor state in i^{-th} descriptor divided by the total number of characterized plants).

The genotype and phenotypic co-efficient of variations were calculated as per by Burton (1952). Heritability in broad sense (H) was estimated by the formula given by Hanson et al (1956). The expected genetic advance (GA) was calculated by the formula as suggested by Johnson et al (1955) and Lush (1949). Direct and indirect effects of component traits on marketable fruit yield were calculated through path coefficient analysis as suggested by Dewey and Lu (1940). The grouping of the populations was done by using Tocher's method as described by Rao (1952). Hierarchical cluster analysis has been done with those same genotypes in order to observe the degree of association according to their characteristics that was expressed in dendrogram following Ward's (1963) method. Principal component analysis (PCA), to identify the factor dimension of the data, was used to summarize varietal information in a reduced number of factors for selection of the best performing genotypes. Statistical analyses were with Windostat (ver.8.0, Indostat Services, Hyderabad, India). Treatment means were separated using Least Significant Differences following Tukey's post hoc test.

RESULTS AND DISCUSSION

Morphological characterization of genotypes: Seven qualitative characters *viz*., plant growth habit, leaf shape, flower position, corolla colour, male sterility, fruit colour and fruit shape were recorded in 21 genotypes of sweet pepper as per the minimal descriptors of NBPGR to characterize the present diversity of sweet pepper (Table 1). In the present investigation two types of growth habit was found *viz*. erect and intermediate. All the genotypes except the Royal Wonder showed erect growth habit (95.23%). The genotype Royal Wonder exhibited intermediate (4.76 %) growth habit. Leaf shape of different sweet pepper genotypes were grouped into three categories *viz*. deltoid, ovate and lanceolate. Out of 21 genotypes, 42.85 % genotypes showed deltoid type, 47.61 % showed ovate and 9.52 % genotypes showed lanceolate type of leaf shapes. Out of 21 genotypes, 10 genotypes exhibited pendent position (47.61 %), 8 genotypes in intermediate position (38.09 %) and 3 genotypes exhibited upright flower position (14.28 %). The genotypes were grouped into 12 categories according to the Royal Horticultural Society Colour Chart (RHCC). Four genotypes each were grouped into Red Group 42A and Red Group 45A (Table 1). Under Red Group 46A, two genotypes were identified. One genotype was categorized into Orange Red Group 34A group. One genotype each was grouped into Yellow Orange Group 17A, Yellow Orange Group 21A and Yellow Orange Group 23A. Two genotypes were categorized into Green Group N137B and Green Group 141B. One genotype was categorized under Green White Group 157C group. One genotype each was grouped under Purple Group N77A and Yellow Group 10 A. Fruit shape of different sweet pepper genotypes were grouped into three categories *viz*. blocky, elongate and almost round. Out of 21 genotypes 85.71 % genotypes showed blocky type of fruit shape and 9.52 % revealed elongate type of fruit shape. Only one genotype Royal Wonder showed almost round type (4.76 %) of fruit shape. Characterization of sweet pepper genotypes has been a determinant factor to gain new insights into genes and mechanisms involved in plant morphology.

Shannon-Weaver Diversity Index of 21 sweet pepper genotypes was estimated from 5 qualitative characters and results are presented in Table 2. High Shanon-Wiener diversity index with an overall mean of 70.71 % was obtained, supporting the existence of diversity among the sweet pepper genotypes. In the present study Shannon-Wiener diversity index H' value varied from 0 to 2.318. The character fruit colour showed maximum diversity (2.318) followed by flower position (0.998), leaf shape (0.940) and fruit shape (0.707). Corolla colour and male sterility did not show any diversity among the genotypes.

Frequency distribution of different traits showed a considerable variation present in the population. Leaf shape, flower position, fruit colour and fruit shape showed higher variation than other characters. Selection could be useful for the trait fruit colour and fruit shape to develop attractive sweet pepper variety. Roy et al (2019) also reported such type of fruit colour and fruit shape.

Table 1. Qualitative parameters of 21 sweet pepper genotypes

Genotype	Plant growth habit	Leaf shape	Flower position	Fruit colour*	Fruit shape
C/4	Erect	Ovate	Intermediate	Red Group 42A	Blocky
8/4	Erect	Deltoid	Pendent	Orange Red Group 34A	Elongate
Arya	Erect	Deltoid	Intermediate	Red Group 45A	Blocky
Baby Bell	Erect	Deltoid	Intermediate	Red Group 42A	Blocky
BC CAP Purple	Erect	Ovate	Pendent	Purple Group N77A	Blocky
Royal Wonder	Intermediate	Deltoid	Intermediate	Green Group N137B	Almost round
BC CAP White	Erect	Deltoid	Pendent	Green White Group 157C	Blocky
BC CAP Green	Erect	Lanceolate	Pendent	Green Group 141B	Blocky
BC CAP Red	Erect	Lanceolate	Pendent	Red Group 45A	Blocky
Fiza (DG)	Erect	Ovate	Pendent	Red Group 46A	Blocky
Fiza (LG)	Erect	Ovate	Pendent	Red Group 45A	Blocky
Ayesha	Erect	Deltoid	Intermediate	Red Group 45A	Blocky
BC CAP Yellow	Erect	Deltoid	Pendent	Yellow Orange Group 17A	Blocky
Arka Mohini	Erect	Deltoid	Pendent	Green Group 141B	Blocky
Arka Basant	Erect	Ovate	Upright	Yellow Group 10 A	Blocky
Arka Gaurav	Erect	Ovate	Upright	Yellow Orange Group 21A	Blocky
BC CAP Orange	Erect	Deltoid	Pendent	Yellow Orange Group 23A	Blocky
2018/CAP 2	Erect	Ovate	Intermediate	Red Group 42A	Blocky
2018/CAP 3	Erect	Ovate	Intermediate	Yellow Orange Group 23A	Blocky
2018/CAP 4	Erect	Ovate	Upright	Red Group 42A	Elongate
2018/CAP 5	Erect	Ovate	Intermediate	Red Group 46A	Blocky

*Royal Horticulture Society (RHS) Colour Chart

Table 2. Frequency distribution for different qualitative characters in sweet pepper genotypes

Character	Specification	No. of genotypes	Percentage of genotypes (%)	H'-index
Plant growth habit	Erect	20	95.23	0.191
	Intermediate	1	4.76	
Leaf shape	Deltoid	9	42.85	0.940
	Ovate	10	47.61	
	Lanceolate	2	9.52	
Flower position	Pendent	10	47.61	0.998
	Intermediate	8	38.09	
	Upright	3	14.28	
Fruit colour	Red Group 42A	4	19.04	2.318
	Red Group 45A	4	19.04	
	Red Group 46A	2	9.52	
	Orange Red Group 34A	1	4.76	
	Green Group N137B	1	4.76	
	Green Group 141B	2	9.52	
	Yellow Orange Group 17A	1	4.76	
	Yellow Orange Group 21A	1	4.76	
	Yellow Orange Group 23A	2	9.52	
	Yellow Group 10 A	1	4.76	
	Green White Group 157C	1	4.76	
	Purple Group N77A	1	4.76	
Fruit shape	Blocky	18	85.71	0.501
	Elongate	2	9.52	
	Almost round	1	4.76	
Overall mean of H'				0.707

Biodiversity in crops can be summarized with two of its components, allelic evenness and allelic richness. The descriptor and descriptor states are parallel to the locus and alleles, respectively in morphological evaluation. The allelic evenness in this study was measured using the Shannon-Wiener Diversity Index, whereas the allelic richness was measured by counting the descriptor states for each descriptor without considering their individual frequencies. The richness indicates the number of genotype present in a designated area whereas evenness stands for the relative abundance of each genotype. The value of Shannon-Wiener diversity index (H') for all characters varied from 0 to 2.318. High Shanon-Wiener diversity index with an overall mean of 70% was obtained, confirming the existence of diversity among the genotypes. The predominant traits that showed wider variations among the genotypes were fruit colour, followed by flower position, leaf shape and fruit shape. The Shannon-Wiener index values can range from 0 to ~ 4.6. A value near 0 indicated that every genotype in the sample is the same and a value near 4.6 indicated the numbers of individual are evenly distributed between the sweet pepper genotypes. A low H' indicates unbalance frequency class and lack of diversity for the traits for corolla colour and male sterility mechanism. A higher H' value indicates presence of variability or diversity for the trait (Hennink and Zeven 1991). Values below overall mean indicate unbalance frequency class and lack of diversity for the traits. Belay and Tsehaye (2020) also studied the Shanon-Wiener diversity index and they observed highly divergent qualitative traits of 63 hot pepper Ethiopian landraces.

Mean performance of genotypes: The character plant height was influenced significantly by the genotypes under study (Table 3). The genotype BC CAP Orange showed maximum plant height followed by Ayesha and BC CAP Yellow. The minimum plant height was observed in Arka Gaurav (83.16 cm) and 2018/CAP 5 (83.16 cm). Early

Table 3. Mean performance of twenty one sweet pepper genotypes

Genotype	Plant height (cm)	Days to first flowering	Days to 50% flowering	Days to first harvest	Number of primary branches/plants	Fruit length (cm)	Fruit diameter (cm)	Shape index	Pericarp thickness (mm)
C/4	109.38	42.67	48.33	128.00	2.33	8.75	7.18	1.22	5.22
8/4	86.02	44.67	52.67	108.67	2.50	11.93	5.46	2.19	5.17
Arya	120.70	33.33	41.67	130.33	2.50	10.44	6.15	1.69	5.92
Baby Bell	126.14	46.00	48.00	124.33	2.50	7.98	7.27	1.10	5.04
BC CAP Purple	120.00	53.00	70.67	126.33	2.00	8.69	6.45	1.35	4.50
Royal Wonder	95.69	40.33	46.00	130.00	3.50	9.14	8.32	1.11	5.96
BC CAP White	89.05	40.00	42.33	105.00	2.50	7.36	5.47	1.39	6.96
BC CAP Green	99.66	36.00	54.67	135.67	2.50	9.40	7.05	1.34	5.81
BC CAP Red	104.83	43.33	55.67	138.00	2.17	9.32	6.79	1.37	5.90
Fiza (DG)	103.11	43.00	65.67	126.33	2.33	10.03	5.51	1.83	3.96
Fiza (LG)	123.44	45.00	60.67	122.00	2.33	6.91	4.68	1.48	5.28
Ayesha	141.77	37.33	48.67	136.67	2.00	11.12	4.76	2.34	5.73
BC CAP Yellow	132.50	34.00	50.67	122.33	2.33	8.22	6.60	1.26	5.18
Arka Mohini	85.83	40.67	48.33	136.00	3.00	10.44	7.28	1.44	6.57
Arka Basant	86.16	52.00	74.67	136.33	2.83	7.48	5.28	1.43	5.70
Arka Gaurav	83.16	46.00	48.67	134.33	3.00	10.31	6.68	1.55	5.46
BC CAP Orange	146.77	43.00	54.67	134.67	2.83	8.86	6.70	1.32	5.78
2018/CAP 2	105.00	47.33	75.33	137.67	2.17	6.73	5.03	1.36	3.26
2018/CAP 3	83.66	50.00	78.00	138.33	2.17	6.48	5.29	1.22	3.23
2018/CAP 4	90.61	48.00	74.33	140.00	2.00	9.66	3.99	2.43	5.30
2018/CAP 5	83.16	54.67	80.67	133.67	2.17	8.46	5.40	1.57	3.54
Mean	105.56	43.83	58.11	129.75	2.46	8.94	6.06	1.52	5.21
								0.11	0.33
C.D. at 5%	16.73	5.19	4.98	8.04	0.40	1.27	0.87	0.31	0.94
C.V. (%)	9.61	7.17	5.19	3.75	9.77	8.61	8.73	12.28	10.95

flowering leads to early and higher production of fruit which can fetch higher market price.Days to first flowering and days to 50% flowering are the main traits to judge earliness of the genotypes. In the present investigation, the genotype Arya takes minimum days (33.33 days) to open first flower followed by BC CAP Yellow and BC CAP Green . The maximum days taken to first flowering was in 2018/CAP 5 (54.67 days) followed by BC CAP Purple. The minimum days to produce 50% flowering was taken by the genotype Arya (41.67 days) followed by BC CAP White, Royal Wonder. The genotype BC CAP White taken minimum days to first harvest (105.00 days) followed by 8/4. The maximum days taken to first harvesting was in 2018/CAP 4 (140 days) followed by 2018/CAP 3. The highest number of primary branches/plants was noticed in the genotype Royal Wonder (3.50) followed by Arka Mohini and Arka Gaurav. The genotype showed maximum fruit length was 8/4 (11.93 cm) followed by Ayesha. The genotype Royal Wonder revealed maximum fruit diameter (8.32 cm) followed by Arka Mohini and Baby Bell. The genotype 2018/CAP 4 produced highest shape index (2.43) followed by Ayesha and 8/4 . The thickest pericarp was documented in BC CAP White (6.96 mm) followed by Arka Mohini and Royal Wonder (Table 3). The minimum number of locule/fruit was in 2018/CAP 2 (2.00) followed by 2018/CAP 5 (Table 4). The maximum number of seeds/fruits was recorded by BC CAP Green (277.67) followed by Fiza (LG) and BC CAP Red. The genotype 8/4 recorded the highest TSS content of fruit (8.91^{0}brix) followed by C/4 . The highest vitamin C content was in C/4 (180.88 mg/100 g) followed by Arka Gaurav. The genotype BC CAP Red recorded the maximum Lycopene content of fruit (3.04 mg/100 g) followed by Baby Bell .The genotype Arya recorded the highest β-carotene (2.74 mg/100 g) followed by Baby Bell . The maximum number of fruits was produced by BC CAP Orange (15.02) followed by Arka Basant. The heaviest fruit was documented in Arka Gaurav (137.68 g) followed by Arka

Table 4. Mean performance of twenty one sweet pepper genotypes

Genotype	Number of locule/ fruit	Number of seeds/ fruits	TSS content of fruit (^{0} brix)	Vitamin C content of fruit (mg/100 g)	Lycopene content of fruit (mg/100 g)	β- carotene content of fruit (mg/100 g)	Number of fruits/ plants	Average fruit weight (g)	Fruit yield/ plant (kg)
C/4	3.70	154.04	8.44	180.88	1.07	2.39	9.34	112.01	1.05
8/4	3.13	104.56	8.91	138.85	1.62	2.12	9.00	87.01	0.79
Arya	3.43	77.03	6.90	146.34	2.00	2.74	8.34	108.02	0.90
Baby Bell	3.33	105.14	6.74	175.19	2.25	2.59	7.34	90.04	0.65
BC CAP Purple	3.67	152.50	7.11	126.98	0.16	0.21	6.33	73.02	0.46
Royal Wonder	3.40	160.96	5.61	123.09	0.21	0.16	6.67	120.03	0.80
BC CAP White	3.64	77.26	6.64	178.87	0.06	0.09	6.00	78.09	0.47
BC CAP Green	3.67	277.67	4.30	119.28	0.31	0.31	6.50	115.43	0.75
BC CAP Red	4.01	218.78	7.93	171.38	3.04	1.43	7.50	98.03	0.73
Fiza (DG)	3.00	48.72	7.30	148.24	1.08	0.92	10.50	53.59	0.56
Fiza (LG)	2.67	263.48	6.40	155.72	1.78	1.56	11.62	50.32	0.58
Ayesha	3.00	91.22	7.60	159.64	1.31	1.01	10.50	107.14	1.13
BC CAP Yellow	3.00	101.74	8.00	178.87	0.14	0.66	9.00	94.47	0.85
Arka Mohini	3.67	144.71	8.20	173.10	0.11	1.14	8.01	131.33	1.05
Arka Basant	2.67	115.72	6.73	138.52	0.30	0.42	13.76	54.48	0.75
Arka Gaurav	3.67	52.35	8.20	180.82	0.23	0.61	6.01	137.68	0.83
BC CAP Orange	3.34	160.71	7.53	172.39	1.02	0.76	15.02	80.75	1.21
2018/CAP 2	2.00	83.43	7.13	55.84	0.20	0.27	10.02	41.08	0.41
2018/CAP 3	2.67	197.34	7.20	53.85	0.17	0.39	7.00	55.00	0.39
2018/CAP 4	3.00	123.70	7.30	78.87	0.25	0.40	11.00	46.26	0.51
2018/CAP 5	2.33	85.50	6.57	92.36	0.24	0.29	11.00	47.51	0.52
Mean	3.19	133.17	7.18	140.43	0.84	0.97	9.07	84.82	0.73
								2.01	0.04
C.D. at 5%	0.17	30.52	1.01	9.31	0.07	0.05	1.22	5.76	0.12
C.V. (%)	3.18	13.89	8.55	4.02	5.20	3.39	8.13	4.11	9.59

Mohini. The maximum fruit yield/plant was recorded in BC CAP Orange (1.21 kg) closely followed by Ayesha (Table 4).

Genetic variability and heritability: The result on analysis of variances using randomized block design revealed that the genotypes exhibited highly significant differences for all the characters studied even at 1% level of significance (Table 5) which clearly endorsed the justification of studying genetic variability of different characters employing these genotypes. The estimates of mean, range, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (h^2) and genetic advance as per cent over mean (GAM) were worked out for 18 characters of 21 sweet pepper genotypes (Table 6).

The knowledge of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is much helpful in predicting the amount of variation present in a given assemblage of genotypes. The estimates of phenotypic co-efficient of variation (PCV) and genotypic co-efficient of variation (GCV) in the present investigation for all characters under study were very close but PCV was higher than GCV (Table 6). The value of GCV ranged from 6.91% (days to first harvest) to 103.72% (lycopene content of fruit). On the other hand PCV ranged from 7.86 % (days to first harvest) to 103.85 % (lycopene content of fruit). High GCV values (>20.00 %) were documented for the traits days to 50 % flowering, shape index, number of seeds/fruits, vitamin-C content of fruit, lycopene content of fruit, β-carotene, number of fruits/plants, average fruit weight, fruit yield/plant. Moderate GCV values (10-20 %) were recorded for the traits plant height, days to first flowering, number of primary branches/plant, fruit length, fruit diameter, pericarp thickness, number of locule/fruit and TSS content of fruit. Likewise, high PCV values (>20.00 %) were recorded for plant height, days to 50% flowering, shape index, pericarp thickness, number of seeds/fruit, Vitamin-C content of fruit, lycopene content of fruit, β-carotene, number of fruit/plant, average fruit weight and fruit yield/plant, whereas days to first flowering, number of primary branches/plant, fruit length, fruit diameter, number of locule/fruit, and TSS content of fruit showed moderate PCV (10-20 %). The proportion of GCV to PCV noticed in this investigation ranged from 83.25% in number of primary branches/plant to 99.85% in β-carotene content. GCV alone do not estimate the variations that are heritable for this reason, estimation of heritability becomes essential. High broad sense heritability (60 % and above) was recorded for most characters under study. High magnitude (>20.00 %) of genetic advance as per cent of mean was observed for most traits under study except days

Table 5. Analysis of variance (mean square) for 18 characters of sweet pepper genotypes

Source of variation	Mean sum of square		
	Replication	Treatments	Error
Degrees of freedom	2	20	40
Plant height (cm)	1.4848	1229.4362**	102.8202
Days to first flowering	3.3492	104.6540**	9.8825
Days to 50% flowering	3.9206	481.8111**	9.1040
Days to first harvest	3.4444	264.5302**	23.7111
Number of primary branches/plants	0.1243	0.4492**	0.0578
Fruit length (cm)	1.5203	6.5358**	0.5919
Fruit diameter (cm)	0.5398	3.5402**	0.2801
Shape index	0.0044	0.4262**	0.0350
Pericarp thickness (mm)	0.1244	3.0543**	0.3257
Number of locule/fruit	0.0134	0.7938**	0.0103
Number of seeds/fruits	1.1092	12182.0462**	341.9874
TSS content of fruit (^{0} brix)	0.3755	3.1096**	0.3764
Vitamin-C content of fruit (mg/100 g)	7.0351	4929.8251**	31.7973
Lycopene content of fruit (mg/100 g)	0.0006	2.2553**	0.0019
β- carotene content of fruit (mg/100 g)	0.0001	2.1462**	0.0011
Number of fruits/plants	0.8325	18.9603**	0.5431
Average fruit weight (g)	34.4900	2726.8796**	12.1734
Fruit yield/plant (kg)	0.0007	0.1741**	0.0049

** Significant at 0.01 level of probability

to first harvest which showed moderate magnitude of GA (Table 6).

The difference between phenotypic co-efficient of variation (PCV) and genotypic co-efficient of variation (GCV) for most characters under study was very close suggesting less influence of environment for the expression of characters. High magnitude of GCV and PCV was observed in days to 50% flowering, shape index, number of seeds/fruits, vitamin-C content of fruit, lycopene content of fruit, β-carotene content of fruit, number of fruits per plant, average fruit weight and fruit yield/plant indicating ample scope for the improvement of such traits through simple selection. Similar findings were reported by Rana et al (2015), Anuradha and Sood (2019) and Thakur et al (2019). In this investigation, the proportion of GCV to PCV illustrate that genetic contribution to the overall phenotypic expression of most traits was high. Therefore, their use as important discriminatory variables for sweet pepper classification study seems relatively dependable.

High broad sense heritability was recorded for all the characters indicated that selection based on phenotypic expression could be dependable as there was major role of genetic constitution in the expression of these characters. High magnitude (>60.00 %) of heritability estimates had also been reported earlier by Rana et al (2015), Anuradha and Sood (2019) and Thakur et al (2019) in sweet pepper. In the present study, high heritability coupled with high genetic advance as per cent of mean was observed for all the traits under study except days to first harvest. These characters can be regarded as most reliable for selection because these characters are controlled by additive gene action and selection of these traits would be rewarding for the improvement of these traits. Such observations find support for plant height, days to 50% flowering, number of primary branches/plant, TSS content of fruit (Thakur et al 2019); fruit length (Anuradha and Sood 2019); fruit diameter (Pandey et al 2013); Vitamin-C content of fruit (Anuradha and Sood 2019, Thakur et al 2019); number of fruits/plant (Rana et al 2015); average fruit weight (Pandey et al 2013, Sharma et al 2017); fruit yield/plant (Rana et al 2015, Sharma et al 2017, Thakur et al 2019).

Correlation analysis: Association analysis of different morphological characters with fruit yield of sweet pepper genotypes and their inter-relationships were investigated

Table 6. Genetic parameters of sweet pepper genotypes and genotypic and phenotypic correlations and direct effects of 17 characters on fruit yield /plant

Character	GCV* (%)	PCV* (%)	GCV:PCV	h^2 in broad sense (%)	Genetic advance as % of mean	rg with fruit yield/plant	rp with fruit yield/plant	Direct effect of characters on fruit yield/plant at phenotypic level
Plant height (cm)	18.36	20.72	88.60	78.51	33.51	0.477*	0.377	0.071
Days to first flowering	12.82	14.69	87.28	76.17	23.06	-0.576**	-0.486*	-0.028
Days to 50% flowering	21.60	22.22	97.23	94.54	43.27	-0.638**	-0.587**	-0.118
Days to first harvest	6.91	7.86	87.86	77.20	12.50	0.136	0.143	-0.070
Number of primary branches/plants	14.68	17.64	83.25	69.30	25.18	0.443*	0.357	-0.100
Fruit length (cm)	15.75	17.95	87.75	77.00	28.47	0.586**	0.473*	0.073
Fruit diameter (cm)	17.19	19.28	89.17	79.50	31.57	0.460*	0.381	-0.045
Shape index	23.71	26.70	88.80	78.86	43.38	0.069	0.054	-0.129
Pericarp thickness (mm)	18.30	21.33	85.81	73.63	32.35	0.591**	0.497*	-0.020
Number of locule/fruit	16.02	16.33	98.09	96.22	32.37	0.413	0.404	0.090
Number of seeds/fruits	47.18	49.18	95.93	92.03	93.23	0.003	0.005	0.008
TSS content of fruit (^{0} brix)	13.30	15.81	84.12	70.77	23.04	0.329	0.286	0.091
Vitamin-C content of fruit (mg/100 g)	28.77	29.05	99.04	98.09	58.70	0.634**	0.601**	-0.168
Lycopene content of fruit (mg/100 g)	103.72	103.85	99.87	99.75	213.40	0.230	0.217	-0.020
β- carotene content of fruit (mg/100 g)	86.79	86.86	99.92	99.85	178.65	0.389	0.368	-0.001
Number of fruits/plants	27.32	28.50	95.85	91.87	53.94	0.248	0.301	0.885
Average fruit weight (g)	35.46	35.70	99.33	98.67	72.57	0.687**	0.665**	1.038
Fruit yield/plant (kg)	32.38	33.77	95.88	91.93	63.95	-	-	-

*GCV = Genotypic coefficient of variation; PCV = Phenotypic coefficient of variation,h^2 = Heritability estimatein broad sense, rp = Phenotypic correlation coefficient; rg = Genotypic correlation coefficient *, ** Significant with $P \leq 0.05$ and 0.01, respectively
Residual effect= 0.021

through the study of both phenotypic and genotypic correlation co-efficient (Table 6). The genotypic and phenotypic correlation co-efficient agreed very closely for most traits under study. In general, the genotypic correlations were higher than the phenotypic ones. The characters plant height, number of primary branches/plants, fruit length, fruit diameter, pericarp thickness, vitamin-C content of fruit, and average fruit weight showed positive significant genotypic correlations with fruit yield/plant. Shape index, number of locules/fruit, number of seeds/fruits, number of fruits/plants, TSS content of fruit, lycopene content of fruit, and β-carotene content of fruit showed positive but non-significant correlations with fruit yield/plant. The negative significant genotypic correlation was found by two characters namely, days to first flowering and days to 50% flowering. Besides, genotypic correlation, the traits fruit length, pericarp thickness, vitamin-C content of fruit, and average fruit weight expressed positive significant phenotypic correlations with fruit yield/plant. Plant height, number of primary branches/plant, fruit diameter, shape index, number of locules/fruit, number of seeds/fruits, number of fruits/plants, TSS content of fruit, lycopene content of fruit and β-carotene content of fruit showed positive but non-significant phenotypic correlations with fruit yield/plant. Besides, days to first flowering and days to 50% flowering exhibited negative significant phenotypic correlation coefficients with fruit yield/plant.

Close values of genotypic and phenotypic correlation co-efficient demonstrating little control of environment on the correlated response on most of the pair of fruit and fruit quality characters. From the result of genotypic and phenotypic correlation co-efficient suggested that fruit yield/plant can be increased through increase in important component traits like fruit length, pericarp thickness, vitamin-C content of fruit and average fruit weight. An inverse correlation was also found between days to first flowering and days to 50% flowering with yield indicating early flowering genotype gives more yield than the late one. Therefore, selection for the earliness traits would automatically improve the yield. Afroza et al (2013) reported positive significant correlation of fruit length with fruit yield/plant. Positive significant correlation of average fruit weight (Afroza et al 2013, Sharma et al 2017, Thakur et al 2019) with fruit yield/plant also supported the present findings. Inverse correlation of the traits days to first flowering (Afroza et al 2013) with fruit yield/plant had also been reported.

Path co-efficient analysis: The result showed that, among the yield component traits, number of fruits/plant (0.885) and average fruit weight (1.038) showed high positive direct effects on fruit yield/plant (Table 6). The direct effects of other traits as well as their indirect effects *via* other characters were negligible. Some other characters like plant height,fruit length, number of locules/fruit, number of seeds/fruit and TSS content of fruit also showed direct positive effects on fruit yield but their magnitude was very low. Rest of the characters showed negative direct effects on fruit yield/plant. Residual effect of the path analysis was very low (0.021). Number of fruits/plant and average fruit weight exhibited high positive direct effects on fruit yield/plant. This was the main cause of their positive association with fruit yield/plant. These results are in conformity with the observations of Sharma et al (2010) and Thakur et al (2019). Hence, direct selection through number of fruits/plant and average fruit weight could be beneficial for yield improvement of sweet pepper. Residual effect of the path analysis was very low suggesting the inclusion of maximum fruit yield determining characters in the present study. From the study of character association ships, combining both correlation and path co-efficient, two characters namely, number of fruits/plant and average fruit weight should be considered as important selection indices for yield improvement of sweet pepper as they showed positive correlation and high direct effects on fruit yield per/plant.These observations find support from Afroza et al (2013), Roy et al (2019) and Thakur et al (2019).

Genetic diversity through multivariate analysis: The present study aimed at analyzing the genetic divergence of 21 sweet pepper genotypes employing 18 important quantitative characters. Based on the degree of divergence (D^2 values) between any two genotypes a logical grouping of the genotypes with low D^2 value could be arrived at by Tocher's method as described by Rao (1952). Based on determination of divergence, all the 21 genotypes were grouped into 5 clusters by treating estimated D^2 values as the square of the generalized distance (Table 7). Cluster III was the largest having 9 genotypes (BC CAP Purple, BC CAP White, Royal Wonder, BC CAP Green, 2018/CAP-2, 2018/CAP-3, 2018/CAP-4, 2018/CAP-5, Arka Basant) followed by cluster I with 4 genotypes (C/4, 8/4, Arya, Baby Bell). Cluster IV (Fiza (DG), BC CAP Orange, Ayesha) and cluster V (BC CAP Yellow, Arka Gaurav, Arka Mohini) were having 3 genotypes each. Cluster II contained 2 genotypes (BC CAP Red, Fiza (LG)). In further study of Ward's (1963) dendrogram method (Fig. 1) by using squared Euclidean distance, it became clearly evident that there was high genetic diversity among the sweet pepper genotypes along with strong relationships among the genotypes. The intra- and inter-cluster distances among 21 sweet pepper genotypes are presented in Table 7. Among the 5 clusters, cluster II had the maximum intra-cluster value (1402.254)

followed by cluster I (1032.162). Cluster IV showed the minimum intra-cluster value. At inter-cluster level, the maximum inter-cluster value was observed between Cluster I and III (15686.9) followed by between Cluster I and V (10997.850). The minimum inter-cluster value was observed between Cluster III and V (1926.627).

The maximum cluster mean was in cluster V for number of primary branches/plant (2.78), fruit diameter (6.85 cm), pericarp thickness (5.73 mm), number of locule/fruit (3.44), TSS content of fruit (8.13 ^{0}brix), Vitamin-C content of fruit (177.60 mg/100 g) and average fruit weight (121.16 g) (Table 8). The highest cluster mean in cluster IV was for plant height (130.56 cm), fruit length (10.00 cm), shape index (1.83), number of fruits/plant (12.01) and fruit yield/plant (0.97 kg). Highest mean value for the traits number of locule/fruit (3.34) and lycopene content of fruit (2.41 mg/100 g) was shown by cluster II. Cluster I showed maximum mean value for the trait β-carotene content of fruit (2.46 mg/100 g). However, the minimum days taken to first flowering (40.22) revealed by the cluster V whereas, minimum number of days to 50 % flowering (47.67) and first fruit harvest (122.83) showed by the cluster I.The relative contribution of individual characters towards genetic divergence was estimated in terms of number of times it ranked first and is presented in Table 8. Among 18 characters, β-carotene content of fruit (37.62 %) expressed the maximum contribution towards the diversity followed by number of fruits/plant (21.9 %), lycopene content of fruit (13.81 %), average fruit weight (10.95 %), Vitamin C content (9.52 %) and fruit yield/plant (3.33 %).

The PCA was performed to obtain a simplified view of the relationship between the characters β-carotene content, number of fruits/plants, lycopene content of fruit and average fruit weight which explained almost 100% contribution towards divergence and variable loadings for components PC_1 (β-carotene content of fruit), PC_2 (number of fruits/plant), PC_3 (lycopene content of fruit) and PC_4 (fruit weight) were estimated (Table 9). These components were chosen because their eigenvalues were more than 1.0 and explained almost 100.00 % of total variance. The first component (PC1) explained 81.65 % of total accounted for variance in which an increase of β-carotene content of fruit content leads to increase in lycopene content of fruit and fruit weight, and decrease in amount of fruits/plant. The second component (PC2) explained an additional 18.13 % of the variance in which a decrease in number of fruits/plants leads to decrease in β-carotene content of fruit and lycopene content of fruit, and increase in fruit weight. The third component (PC3) explained an additional 0.16 % of the variance in which an increase in lycopene content of fruit leads to increase in β-carotene content, number of fruits/plant and average fruit weight (Table 9). Genotypes in close proximity are perceived as being similar in PCA; Genotypes that are further apart are more diverse. The differences observed in the data, and summarized in the PCA (Fig. 2), indicated genotypes Royal Wonder, BC CAP Green, Arya, 2018/CAP-3, Arka Mohini, Arka Gaurav, Fiza (LG), Fiza (DG), Arka Basant, BC CAP White, BC CAP Orange and Baby Bell were quantitatively dissimilar from others. The remainder of genotypes had similar features forming a separate cluster.

In the present study, 21 sweet pepper genotypes employing 18 important quantitative characters were grouped into 5 clusters based on the degree of divergence (D^2 values) between any two genotypes a logical grouping of the genotypes with low D^2 value could be arrived at by

Table 7. Cluster classification and inter-and intra-cluster distances of 21 sweet pepper genotypes

Clusters with the number of genotypes in parentheses	Name of the genotype with source of collection	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Cluster I (4)*	C/4 (BCKV, W.B.), 8/4 (BCKV, W.B.), Arya (BCKV, W.B.), Baby Bell (BCKV, W.B.)	**1032.162****	4155.689	15686.900	7044.672	10997.850
Cluster II (2)	BC CAP Red (BCKV, W.B.), Fiza (LG) (BCKV, W.B.)		**1402.254**	8298.652	2433.589	6629.095
Cluster III (9)	BC CAP Purple (BCKV, W.B.), BC CAP White (BCKV, W.B.), Royal Wonder (BCKV, W.B.), BC CAP Green (BCKV, W.B.), 2018/CAP-2 (IIVR, Varanasi), 2018/CAP-3 (IIVR, Varanasi), 2018/CAP-4 (IIVR, Varanasi), 2018/CAP-5 (IIVR, Varanasi), Arka Basant (IIHR, Bangalore)			**954.417**	2984.470	1926.627
Cluster IV (3)	Fiza (DG) (BCKV, W.B.), BC CAP Orange (BCKV, W.B.), Ayesha (BCKV, W.B.)				**647.289**	1973.834
Cluster V (3)	BC CAP Yellow (BCKV, W.B.), Arka Gaurav (IIHR, Bangalore), Arka Mohini (IIHR, Bangalore)					**897.165**

*Figures in parentheses indicate number of genotypes.**Bold values indicate intra-cluster distance between genotypes

Tocher's method as described by Rao (1952). The grouping pattern of genotypes was observed to be random, indicating no direct relationship was noticed between geographical distribution and genetic distance. Hence, the selection of genotypes for hybridization should be based on genetic divergence rather than geographic diversity. Several earlier studies also reported that different set of sweet pepper genotypes were grouped under 4-6 clusters (Rana et al 2015, Dabral et al 2016, Devi et al 2017, Sharma et al 2017). Cluster II being maximum intra-cluster value followed by cluster I indicating existence of wide genetic divergence among the component genotypes in it as compared to other clusters. Based on inter-cluster distance, maximum inter-cluster value between Cluster I and III followed by between Cluster I and V indicated that the genotypes in these clusters can be used as parents in hybridization programme to develop higher heterotic hybrids and segregating population will expect to give transgressive segregates in the advanced generation. Genetic divergence of sweet pepper using multivariate analysis was earlier studied by Rana et al (2015),

Table 8. Cluster means and per cent contribution towards divergence of 18 characters of sweet pepper genotypes

Character	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	% contribution towards divergence
Plant height (cm)	110.56	114.14	94.78	130.56	100.50	0.00
Days to first flowering	41.67	44.17	46.82	41.11	40.22	0.00
Days to 50% flowering	47.67	58.17	66.30	56.33	49.22	0.00
Days to first harvest	122.83	130.00	131.44	132.56	130.89	0.00
Number of primary branches/plants	2.46	2.25	2.43	2.39	2.78	0.00
Fruit length (cm)	9.78	8.11	8.16	10.00	9.66	0.00
Fruit diameter (cm)	6.51	5.74	5.81	5.66	6.85	0.00
Shape index	1.55	1.42	1.47	1.83	1.42	0.00
Pericarp thickness (mm)	5.34	5.59	4.92	5.15	5.73	0.00
Number of locule/fruit	3.40	3.34	3.01	3.11	3.44	2.38
Number of seeds/fruits	110.19	241.13	141.56	100.22	99.60	0.48
TSS content of fruit (^{0} brix)	7.75	7.17	6.51	7.48	8.13	0.00
Vitamin-C content of fruit (mg/100 g)	160.32	163.55	107.52	160.09	177.60	9.52
Lycopene content of fruit (mg/100 g)	1.73	2.41	0.21	1.14	0.16	13.81
β- carotene content of fruit (mg/100 g)	2.46	1.50	0.28	0.90	0.80	37.62
Number of fruits/plants	8.50	9.56	8.70	12.01	7.67	21.90
Average fruit weight (g)	99.27	74.17	70.10	80.49	121.16	10.95
Fruit yield/plant (kg)	0.85	0.66	0.56	0.97	0.91	3.33

Table 9. Results of principal component analysis (PCA) for characters contributing to divergence in sweet pepper and contribution of diverse traits in the principal components of sweet pepper

Principal components	Eigenvalue %	% Variance	% Cumulative variance	
Eigenvalues and variance accounted for (%) by PCA based on correlation matrix				
PC_1	2090.54865	81.65	81.65	
PC_2	464.19798	18.13	99.79	
PC_3	4.19595	0.16	99.95	
PC_4	1.04796	0.04	99.99	
Variables	PC_1	PC_2	PC_3	PC_4
Factor loadings due to PCs with eigenvalues greater than 1				
β- carotene content of fruit (mg/100 g)	0.007941	-0.003849	0.032368	0.686042
Number of fruits/plants	-0.011586	-0.064189	0.991897	-0.028470
Lycopene content of fruits (mg/100 g)	0.006106	-0.010310	0.008407	0.726529
Average fruit weight (g)	0.523937	0.849507	0.060787	0.001495

Dabral et al (2016), Devi et al (2017) and Sharma et al (2017).

β-carotene content of fruit, number of fruits/plants, lycopene content of fruit, average fruit weight, vitamin C content and fruit yield/plant are the maximum contributing traits towards the diversity indicating the possibility for selection of these characters for the improvement of these traits. In sweet pepper biochemical trait was as important as some morphological traits for measurement of genetic diversity. Similar type of results was also documented previously by Devi et al (2017). Cluster V being the higher yielder and Cluster I early flowering and harvesting type a high yielding early type with better fruit quality could be breed by utilizing genotypes from these two clusters as parents which is based on cluster mean analysis. Based on principal component analysis (PCA), four components (β-carotene content, number of fruits/plants, lycopene content of fruit and average fruit weight) explained almost 100% of total genetic variation in this study. These characters are highly genetic variable and genotype having these characters in different cluster could be used in breeding programme to develop high yielding better quality cultivars in sweet pepper. These variations may suggest the existence of genetic diversity in sweet pepper that can be harnessed to improve the crop. Based on D^2 statistics, principal component analysis and average performance for fruit yield and fruit colour traits, genotypes Arya, Royal Wonder, Baby Bell, BC CAP White, C/4, 8/4, and BC CAP Purple are good candidates for utilization in breeding programme.

Colour development in selected sweet peppers genotypes: In the present study, distinct fruit colour development of 9 selected genotypes has been studied in details (Table 10). All the genotypes were green in different intensities (whitish green, light green, green, and dark green) at the immature stage. Distinct colour in fruits started developing after 19 to 68 days after anthesis depending on the genotype. In genotype C/4, red colour development started from 56 days after anthesis and 8/4 developed orange red (brick colour) colour 50 days after anthesis. In Arya, red colour in fruit started developing 68 days after anthesis, while it was 60 days after anthesis to develop red colour in Baby Bell. The genotype Royal Wonder remained green colour till harvest but if it is allow ripening this genotype develop faded red colour. The inbreed BC CAP Purple developed purple colour 19 days after anthesis which was quite early as compared to other genotypes. The genotype BC CAP White having whitish green colour at immature stage and developed creamy white colour at maturity. BC CAP Yellow and BC CAP Orange developed yellowish orange and orange colour at 64 and 68 days after anthesis, respectively.

Colour development of the whole fruit from the incitation of colour development (breaker stage) of selected genotypes has also been studied. The genotype Baby Bell took minimum days (9 days) to develop colour of the whole fruit followed by 8/4. BC CAP Purple took maximum days (17 days) to develop colour of the whole fruit followed by C/4. The genotype Arya and BC CAP Orange took 13 days to complete colour development from the breaker stage. BC CAP Yellow took 12 days from the breaker stage to complete colour development. Coloured sweet peppers are recognized for their visual appeal, sweet flavor, antioxidant activities, nutritive carotenoids and anti-inflammatory compounds (Park et al 2012). Capsicum species produce fruits that synthesize and accumulate carotenoid pigments, which are responsible for the fruits' yellow, orange and red colours. Chilli peppers have been used as an experimental model for studying the biochemical and molecular aspects of carotenoids biosynthesis. Both chilli and sweet pepper fruits undergo profound morphological, physiological, and metabolic transformations in terms of pigment composition and content during ripening. These changes in fruit

Table 10. Colour development and pigment contents in 9 sweet pepper genotypes

Genotypes	Immature colour	Colour after physiological maturity	Days taken from anthesis to breaker stage	Days taken from breaker stage to full colour development
C/4	Dark green	Red (Red Group 42A)	56c	16a
8/4	Light green	Orange Red (Orange Red Group 34A)	50d	11bc
Arya	Dark green	Red (Red Group 45A)	68aa	13b
Baby Bell	Dark green	Red (Red Group 42A)	60bc	9c
BC CAP Purple	Dark green	Purple (Purple Group N77A)	19e	17a
Royal Wonder	Green	Green (Green Group N137B)	0.000f	0.000d
BC CAP White	Whitish green	White (Green White Group 157C)	0.000f	0.000d
BC CAP Yellow	Dark green	Yellowish orange (Yellow Orange Group 17A)	64ba	12b
BC CAP Orange	Dark green	Orange (Yellow Orange Group 23A)	68aa	13b

[a]Values in columns followed by the same letter are not significantly different, $p< 0.05$, Tukey's post hoc test

composition are affected by the genotype, maturity and growth conditions (Marin et al 2004). According to the most accepted theory, the synthesis of carotenoids in chilli peppers is controlled by three loci: c1, c2 and y. Carotenoids are responsible for a variety of colours in fully mature pepper fruits, ranging from yellow to red, and they are stored in chromoplasts (Deli et al 2001). The carotenoid synthesis pathway begins with the synthesis of phytoene by phytoene synthase during development and ripening pepper fruits (Hirschberg 2001). Several enzymes participating in carotenoids biosynthesis in chilli and sweet pepper fruits have been isolated and characterized, and the corresponding gene sequences have been reported. However, there is currently limited information on the molecular mechanisms that regulate this biosynthetic pathway. In the present investigation, 9 genotypes of different fruit colour were taken for the study of the colour development. All the genotypes except BC CAP White showed different shades of green colour during immature stage. The point of colour change in capsicum (often termed 'breaker') is usually marked by the appearance of small coloured patches or streaks (initially 5-10% of the fruit surface) (O'Donoghue et al 2017). Fruit harvested with 80% colour coverage can continue to develop full, even colour. Colour development is affected by light and temperature. Degradation of chlorophyll and development of carotenoids pigments (breaker stage) started to develop 50 to 68 days after flowering. However, in the case of BC CAP Purple, anthocyanin pigment development started quite early 19 days after flowering. Red colour development in fruits takes 9-16 days to complete colour development depending upon genotypes, whereas, purple colour development require more days (17 days) compare to red coloured genotypes. Yellow and orange colour development was quite similar to red colour development. β-carotene and lycopene content of fruit decides the different fruit colour of sweet pepper fruit. Here, out of 9 genotypes C/4, 8/4, Arya and Baby Bell having red colour and their β-carotene content was comparatively more than the lycopene content suggested that the red colour of fruit is due to the presence of more β-carotene in the fruit. A single gene *B* (high beta carotene content complementary with another gene *t*) is responsible for the development of red colour in pepper (Lippert et al 1965). The fruit BC CAP White possessed very low amount of β-carotene and lycopene due to the fact that this genotype produces white colour fruit. However, BC CAP Purple showed high amount of anthocyanin pigment in their fruit which resulted deep purple colour fruit. In case of BC CAP Yellow genotype, β-carotene and lycopene content of fruit is comparably lower than other red colour fruit which revealed that the yellow colour development of fruit is due to the pigments other than β-carotene and lycopene. In this case, gene *y* (Lippert et al 1965) is responsible for the development of yellow colour. In BC CAP Orange, lycopene content of fruit is higher than the β-carotene content which suggested that more lycopene is necessary for the development of orange colour fruit. β-carotene is the precursor for the predominant orange and red pigments in sweet pepper and genotypes with high concentrations of β-carotene proved to be richest in total carotenoid content. Therefore, β-carotene may be a

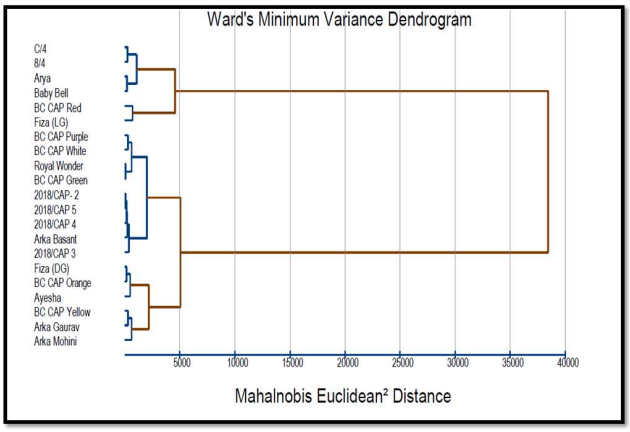

Fig. 1. Dendrogram of 21 genotypes of Sweet pepper following Ward's method

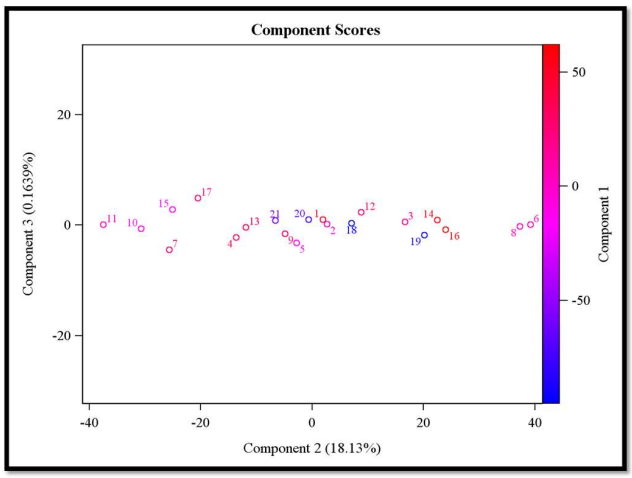

Fig. 2. Scatter diagram of regression factor scores for the first, second and third components as determined by principal component analysis. Points in diagram closest to the intersection of 0 on the X- and Y-axes indicate similarity. Outliers on the X-axis, that is, 6 = Royal Wonder, 8 = BC CAP Green, 3 = Arya, 19 = 2018/ CAP-3, 14 = Arka Mohini, 16 = Arka Gaurav, 11 = Fiza (LG), 10 = Fiza (DG), 15 = Arka Basant, 7 = BC CAP White, 17 = BC CAP Orange, 4 = Baby Bell, indicate diversity. Numbers correspond to the name of the genotype (Fig. 1)

selection criterion for developing highly coloured sweet pepper. The genotype Royal Wonder retained its green colour for longer time. It may be due to the expression of the chlorophyll retainer (*cl*) capsicum is mutated in the STAY-GREEN gene and ripening-related chlorophyll breakdown is prevented (Borovsky and Paran 2008).

CONCLUSIONS

The present study illustrated significant variation among sweet pepper genotypes for growth, yield components and quality traits. High Shanon-Wiener diversity index also suggest the existence of diversity among the sweet pepper genotypes for the morphological traits. Characters such as number of fruits/plant and average fruit weight should be considered the most important indicators of choice to enhance fruit yield. Based on multivariate analysis and average values the sweet pepper genotypes , 'C/4' (Red Group 42A, blocky), '8/4' (Orange Red Group 34A, elongate), 'Arya' (Red Group 45A, blocky), 'Baby Bell' (Red Group 42A, blocky), 'BC CAP Purple' (Purple Group N77A, blocky), 'BC CAP Yellow' (Yellow Orange Group 17A, blocky) and 'BC CAP White' (Green white Group 157 C, blocky) could be utilized as donor parents for developing hybrids, or to isolate promising lines with superior horticultural traits, suitable for growing under protected structure.

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Evaluation of Turmeric Cultivars for Curcumin under Konkan Condition, Maharashtra, India

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***Abstract*:** The experiment was undertaken to screen the different cultivars of turmeric on the basis of curcumin content under Konkan condition. The eight cultivars having high curcumin *viz*., Roma, Pragati, Waigaon, Megha-1, BSR-2, Prathibha, Salem and Phule Swarupa were screened. The various growth parameters, yield parameters, curcumin and essential oil were considered for screening. Upon screening for different parameters, Pragati early variety having high curcumin and essential oil was suitable for the Konkan region.

Keywords: Turmeric, Curcumin, Essential oil, Konkan region, Cultivars screening

Turmeric (*Curcuma longa* L.), known as golden spice, is one of the important crops of Maharashtra. The area under turmeric in Konkan region is increasing as it is nine months crop which escapes water shortage period during the summer. It is shade loving crop and sustains well under partial shade (Singh and Edison 2003). The cultivation of turmeric as intercrop in the coconut and arecanut gardens helps to farmers in Konkan region for getting additional returns. Presently the marketing of turmeric is done based on size and shape. In the new era of marketing the demand of turmeric in the international market on the basis of curcumin content is increasing as 'curcumin' is having its own medicinal uses. In Maharashtra, Salem variety have major share in the turmeric cultivation and curcumin content of this variety is ranging from 3.5 to 4.5 % (Salimath et al 2014). The extraction of the curcumin from the Salem variety is uneconomical as is having less curcumin as compared to the other improved varieties. Hence, there is demand from the turmeric processing industries to screen the high curcumin content variety suitable for cultivation in the Maharashtra so that the traditional Salem variety can be replaced by the improved variety. Crop improvement studies undertaken at various research organizations have resulted in the release of several improved varieties (Naidu and Murthy 2013). The commercial improved varieties released by different organizations in turmeric are location specific (Maurya et al 2018). Curcumin content in these varieties is governed by G x E interaction. The soil health is also play an important role (Mondal and Hore 2022). Therefore, screening of high curcumin varieties released by different organizations in India is undertaken to find out the suitable cultivar having highest curcumin content for Konkan region.

MATERIAL AND METHODS

The commercial improved varieties released by different organizations in India were collected and planted at Post Graduate Institute of Post Harvest Technology and Management, Killa Roha , Raigad, Maharashtra, India. The eight high curcumin varieties *viz*., Roma, Pragati, Waigaon, Megha-1, BSR-2, Prathibha, Salem and Phule Swarupa were used for screening. The experiment was carried out in randomized block design with eight treatments and three replications for three consecutive years during 2019 to 2021.

Growth parameters observed were leaf area (cm^2), leaf area index, number of tillers $plant^{-1}$, number of leaves main $shoot^{-1}$, height of plant 150 days after planting (cm) and duration (days) of the variety. The leaf area was measured with the help of leaf area meter. The yield parameters recorded were weight of mother rhizome $plant^{-1}$(g), number of primary rhizomes $plant^{-1}$, weight of primary rhizomes $plant^{-1}$(g), number of secondary rhizomes $plant^{-1}$, weight of secondary rhizomes $plant^{-1}$(g), fresh yield (q ha^{-1}), dry rhizome yield (q ha^{-1}) and dry recovery percentage. The curcumin was estimated by spectrophotometric method (Geethanjali et al 2016). Percentage curcumin in samples was calculated as: Curcumin % = (Ds x AS/100 x Ws x 1650) x 100; where, Ds- dilution volume of the sample, Ws-weight of the sample, As,-Abosrbance of the sample, 1650-calculated standard value. The essential oil was estimated by steam distillation method (Ching et al 2014).

RESULTS AND DISCUSSION

Growth parameters: The significantly maximum leaf area was of Salem (7815.01 cm^2) followed by Prathibha and Phule

Swarupa and Roma were at par with each other (Table 1). The leaf area index is important indicator of radiation and precipitation, interception, energy conversion and water balance. The significantly maximum leaf area index was of Salem (10.8) and lowest in Waigaon. Leaf area index vary with the variety (Padmapriya et al 2016). The highest number of tillers per plant were observed in Salem (4.1) which was at par with BSR-2, Prathibha, Phule Swarupa, Pragati and Roma. Maximum number of leaves were in Salem (11.8) which was at par with Phule Swarupa, Prathibha and BSR-2. Height at 150 days was maximum of Salem (120.5 cm) which was at par with Phule Swarupa. Waigon matured at minimum days (181 days) after planting which was at par with Pragati. The growth parameters are mainly responsible for vegetative structure of the plant (Li et al 2011).

Yield parameters: The maximum mother rhizome weight (84 g) per plant was of Salem which was at par with BSR-2 (Table 2). The maximum number of primary rhizomes were developed by Salem (4.1) and varieties BSR-2, Prathibha, Phule Swarupa, Pragati and Roma were at par with each other for number of primary rhizomes. Significantly maximum primary rhizomes weight (159.6 g) was attained by Salem followed by Megha-1 and Pragati. The highest number of secondary rhizomes (12.4) per plant were formed in Salem cultivar which was at par with BSR-2, Prathibha, Phule Swarupa, Pragati and Roma. The maximum weight of secondary rhizomes per plant was observed in Salem (403 g) while the varieties BSR-2, Prathibha, Phule Swarupa, Pragati and Roma were at par with each other for secondary weight of rhizomes. The maximum fresh yield of rhizomes was observed in Salem (320.71 q ha^{-1}) which was at par with BSR-2, while the maximum dry yield was in Salem (64.14 q ha^{-1}) which was at par with BSR-2, Prathibha and Pragati. Significantly maximum dry recovery percentage was in Waigaon (22.23 %) followed by Phule Swarupa. The dry recovery percentage of Phule Swarupa, Prathibha, Pragati and BSR-2 were at par with each other. The processing of turmeric has several effects like it promotes gelatinization of starch, increase dehydration rate and distributes pigments uniformly. All these contributes in dry recovery of turmeric (Bambirra et al 2002).

Table 1. Growth performance of different turmeric cultivars grown at Konkan condition

Treatments	Leaf area (cm^2)	Leaf area Index	No of tillers/ plant	No of leaves per main shoot	Plant height (cm) (150 DAP)	Duration (days)
T_1: Roma	7363.07	9.80	3.10	9.40	84.70	246.00
T_2: Pragati	6040.87	8.10	3.20	8.50	101.90	192.00
T_3: Waigaon	5589.93	7.50	2.70	7.70	72.60	181.00
T_4: Megha-1	6960.73	9.30	2.90	9.50	102.50	257.00
T_5: BSR-2	6334.87	8.40	4.00	10.30	104.50	240.00
T_6: Prathibha	7653.67	10.20	3.90	10.40	95.00	221.00
T_7: Salem	8120.87	10.80	4.10	11.80	120.50	264.00
T_8: Phule Swarupa	7510.53	10.00	3.40	10.60	112.50	243.00
CD (p=0.05)	305.85	0.40	1.10	1.53	10.54	11.54

Table 2. Yield contributing and quality parameters of different turmeric cultivars grown at Konkan condition

Cultivars	Mother rhizome Weight g/plant	No. of primary rhizomes/ plant	Primary rhizomes Weight g/plant	No. of secondary rhizomes/ plant	Secondary rhizomes weight g/plant	Fresh rhizome yield q/ha	Dry Rhizome yeld q/ha	Dry recovery (%)	Curcumin (%)	Curcumin yield (kg/ ha	Essential oil (%)	B:C Ratio
T_1	63.00	3.10	98.50	9.20	299.00	228.39	47.58	20.84	4.88	232.04	4.10	1.92
T_2	65.00	3.20	111.60	9.60	312.00	242.35	51.56	21.28	5.55	286.35	5.90	2.54
T_3	42.00	2.70	57.90	8.00	260.00	178.49	38.80	22.23	4.90	190.01	4.90	1.68
T_4	68.00	2.90	112.30	8.80	286.00	231.27	48.18	20.76	4.19	201.88	4.50	1.67
T_5	76.00	4.00	100.50	12.00	390.00	281.00	58.54	21.06	4.07	238.07	3.70	1.97
T_6	49.00	3.90	74.70	11.80	383.50	251.59	53.53	21.28	5.00	267.65	5.80	2.22
T_7	84.00	4.10	159.60	12.40	403.00	320.71	64.14	19.80	4.63	296.77	3.70	2.45
T_8	52.00	3.40	73.60	10.20	331.50	226.72	48.24	21.58	5.10	246.18	4.40	2.04
CD (p=0.05)	12.24	1.10	43.06	3.31	107.51	63.39	13.15	0.60	0.21	65.00	0.40	0.07

See Table 1 for details

Quality parameters: Curcumin is the phenolic compound having medicinal value. The significantly maximum curcumin was in Pragati (5.5 %) followed by Phule Swrupa and Prathibha. The biosynthesis of curcumin take place in shoot and rhizome acts as a storage organ (Pawar et al 2014, Hazra et al 2015 and Kadam et al 2018). The maximum essential oil was in Pragati (5.9 %) which was at par with Prathibha (Ching et al 2014). Chandalinga et al (2016) reported highest curcumin and volatile oil from mother rhizomes. The significantly maximum B:C ratio was recorded in Pragati (2.54) followed by Salem.

CONCLUSIONS

In present study by comparing all the yield contributing and quality parameters as well as B:C ratio of the cultivars under study it was observed that 'Pragati' early variety of turmeric was best suited for higher curcumin and essential oil yield in Konkan condition.

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Morphological and Genetic Variability in French Bean

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***Abstract*:** In the present study, 12 morphological and 13 quantitative characters of French bean were recorded from 16 varieties to assess the genetic variability for growth, yield and quality traits. The overall mean value of Shannon-Weaver diversity index was 0.96 which confirmed the existence of diversity among the genotypes. The genotypes 'Arka Sharath', 'NFL-35' and 'Harsha' were most promising in respect to green pod yield per plant and tolerance to bean anthracnose disease. High phenotypic and genotypic co-efficient of variation were recorded for 10 pod weight, 100 seed weight, protein content of green pod, total sugar content of green pod, PDI of bean anthracnose and pod yield per plant. High heritability coupled with high genetic advance as per cent of mean was observed for pod diameter, number of pods per plant, 10 pod weight, 100 seed weight, number of seeds per pod, protein content, total sugar content of green pod, PDI of bean anthracnose and pod yield per plant indicated that these traits are predominantly governed by additive gene, so early generation selection would be rewarding for improving these traits. Pod diameter, pod length, number of pods per plant and 10 pod weight should be considered as the most important selection indices for enhancing green pod yield in French bean.

Keywords: French bean, Genetic variability, Shannon-Weaver diversity index, Selection indices

French bean (*Phaseolus vulgaris*), commonly known as common bean, snap bean or kidney bean is a widely grown self-pollinated leguminous crop (Kalauni and Dhakal 2020). The genus *Phaseolus* is large, including approximately 80 cultivated and wild species, but *Phaseolus vulgari*s is the most widely cultivated species (Porch et al 2013). The crop is consumed worldwide principally for its green pods, dry (mature) beans and shell beans (seeds at physiological maturity). It is a major source of dietary protein that complements carbohydrate rich sources such as rice, maize, and cassava (Mohammed 2013). It is also a rich source of dietary fibers, minerals, and certain vitamins (Gepts et al 2008). This vegetable not only plays an important role in human nutrition but also improve soil fertility and fits well in crop rotations because of short growing period (Mishra et al 2010). The maximum genetic diversity of wild and cultivated beans is distributed throughout the Americas from northern Mexico through Central America and the Andes to northwest Argentina (Singh et al 1991a). Mexico has been established as the centre of origin, diversification and domestication of the common bean based on ethnobotanical, archaeological, morphological, genetic, biochemical and isoenzyme evidence (Papa et al 2003, Asfaw et al 2009, Bitocchi et al 2012). Domesticated beans are commonly separated into Andean and Mesoamerican gene pools (Singh et al 1991b). This crop is adapted to a wide variety of climatic conditions, being grown from 52° North latitude to 32° South latitude in the humid tropics, semi-arid tropics and even cold climate regions (Panchbhaiya et al 2017).

A wide variety of nutritional compounds with multiple positive effects for human health are contained in bean seeds like high contents of protein, fibre, polyphenols, flavonoids, carotenoids, saponins, oligosaccharides, condensed tannins, lectins, trypsin inhibitors and phytic acid. Polyphenols, anthocyanins and flavonoids among other phytochemical compounds, are particularly related with antioxidant biological activities and preventive effects against chronic degenerative diseases like cancer, obesity and diabetes, cardiovascular diseases as well as other conditions related to the triglycerides, cholesterol and metabolic syndromes (Chavez-Servia et al 2016). At present, the productivity of French bean is quite low (9.84 t/ha) in India (Department of Agriculture and Farmers Welfare, 2021). The probable causes of lower productivity may be unavailability of high yielding and various biotic and abiotic stress resistant varieties. Therefore, much emphasis needs to be given for the development of high yielding and stress resistant varieties and hybrids to increase the productivity comparable to other leading producing countries in the world. Evaluation of the potentialities of the existing genotypes is very necessary because the promise for further crop improvement depends on the genetic diversity of the initial parental materials (Mondal et al 2020). The phenotypic expression of plant character is mainly controlled by genetic makeup of the plant

and the environment, in which it is grown and their interaction between the genotype and environment. Further, variance in any quantitative trait depends on additive (heritable) and non-additive (non-heritable) variance, which include dominance and epistatis (non-allelic interaction). Therefore, it becomes essential to partition the observed phenotypic variability into genotypic (partly heritable) and environmental (non-heritable) components with suitable parameters, such as phenotypic and genotypic co- efficient of variation and heritability in broad sense. Furthermore, genetic advance may be used to predict the efficiency of selection (Jhanavi et al 2018). A measure of heritability and genetic advance gives an idea about the expected gain in the next generation. Green pod yield in French bean is a complex character like other legume vegetables and many morphological and physiological characters constitute it so that high yield can be achieved by selection of those characters that are having high heritability coupled with genetic advance. Assessing direct or indirect effects of each component traits towards green pod yield through path analysis would help in identifying reliable characters contributing to yield (Lyngdoh et al 2017).

MATERIAL AND METHODS

Field experiment was conducted during *rabi* season of 2021-22 at Horticulture Research Farm (HRF) of M S Swaminathan School of Agriculture (MSSSOA), Centurion University of Technology and Management, Paralakhemundi, Gajapati, Odisha. Genotypes of French bean were collected from different places of India constituted the plant materials for this study. The experiment was conducted in randomized complete block design (RCBD) with 16 treatments and 3 replications. The crop was grown in individual plots of 3.6 m × 2.4 m with a spacing of 45 cm × 30 cm from row to row and plant to plant respectively. Standard cultural practices and protective measures recommended in the 'Manual on Agricultural Production Technlogy' (Directorate of Agriculture and Food Production, 2008) were followed to ensure a healthy crop stand.

Observations: The observations on both qualitative and quantitative characters were recorded from 10 randomly selected plants of each plot in each replication.

Qualitative parameters: Qualitative characters like plant growth habit, stem pigmentation, leaf colour, leaflet shape, flower wing colour, pod colour, orientation of pods, pod beak shape, pod shape, pod curvature, pod pubescence and seed colour were recorded.

Quantitative parameters: 13 quantitative traits were recorded. Total soluble protein and sugar content of green pod were estimated as per Lowry et al (1951) and by Anthrone method (Dubois et al 1956) respectively.

Bean anthracnose disease severity: The severity of bean anthracnose [C.O: *Colletotrichum lindemuthianum* (Sacc. and Mang.)] was recorded from each plant of a genotype in each plot starting from seedling to pod maturity stages. Assessment on the reaction of the genotypes to bean anthracnose was recorded with the disease parameter Percent Disease Index (PDI) following the disease rating scale *i.e.* 0-9 (Mayee and Dattar 1986) in Table 1.

Percent Disease Index (PDI) was calculated from the numerical ratings (McKinney 1923).

Statistical analyses: Statistical analyses were done with Windostat (ver.8.0, Indostat Services, Hyderabad, India. The frequency distributions were used to calculate the Shannon-Weaver diversity index (H) for each character (Hennink and Zeven 1991). The index is as follows:

$$H = -\sum_{i=1}^{S} Pi \ln Pi$$

Where,

H= Shannon-Weaver diversity index, S= the number of genera, Pi= ni/N as the proportion of type I (ni= the total number of individuals of microbe in total i type, N= the total number of all the individuals in total n).

The genotype and phenotypic co-efficient of variations were calculated as per Burton (1952). Heritability in broad sense (H) was estimated by the method proposed by Hanson et al (1956). The expected genetic advance (GA) was

Table 1. Disease rating scale (0-9) of bean anthracnose

Symptom severity grade	Symptom	Reaction
0	No symptoms on leaf/pods	Highly resistant (HR)
1	Small, round brown spots covering 1% or less of leaf/pod area	Resistant (R)
3	Brown, sunken spots covering 1-10 % of leaf/pod area	Moderately resistant (MR)
5	Brown spots enlarging to form circular spots covering 11-25% of leaf/pod area	Moderately susceptible (MS)
7	Circular brown, sunken spots, covering 26–50% of leaf/pod area	Susceptible (S)
9	Circular to irregular, brown sunken spots covering 50% or more of the leaf/pod area	Highly susceptible (HS)

Percent Disease Index (PDI) was calculated from the numerical ratings (McKinney 1923).

calculated as per Lush (1949) and Johnson et al (1955). Direct and indirect effects of component traits on green pod yield per plant were calculated through path coefficient analysis (Dewey and Lu 1959).

RESULTS AND DISCUSSION

Morphological characterization of genotypes: 12 morphological/ qualitative characters recorded in 16 bush type genotypes of French bean as per descriptors of NBPGR (Table 2). Frequency distribution patterns, percent of proportion and Shannon-Weaver Diversity Index (H) were estimated from the same 12 characters (Table 3). All the genotypes (100 %) showed bush type of plant growth habit. Genotypes of the present study revealed great variation for the traits stem pigmentation, leaf colour and pod colour where those were grouped into 9 categories according to the Royal Horticultural Society Colour Chart (RHCC). 56.20 % genotypes had round shaped leaflet while 43.70 % genotypes exhibited ovate shaped leaflet. This type of grouping was also reported by Kanwar et al (2019). Flower wing colour of the genotypes varied from 87.50 % genotypes with white colour to only 12.50 % genotypes with deep pink to purple flower wing. Kalauni et al (2019) also reported white and violet-purple colour flower wing of six genotypes of French bean. 13 out of 16 genotypes (81.20 %) showed prostrate pod orientation whereas 3 genotypes had upright orientation. All the genotypes were grouped into 3 categories *viz*., short, medium and long regarding the trait pod beak shape. Out of these genotypes, 5 each was having short (31.20 %) and long pod beak (31.20 %) whereas rest 6 had medium pod beak. Pod shape of different French bean genotypes were grouped into 2 categories *i.e*., straight and

Table 2. Morphological characterization of 16 French bean genotypes

Genotypes	Plant growth characters					Pod characters						
	PGH	SP	LS	LC	FWC	PC	OP	PBS	PS	PCU	PP	SC
Malgudi	Bush type	137 (B)	Round (1.44)	137 (B)	White	137 (B)	Prostrate	Long	Slightly curved	Slightly curved	No hairs	White
Akshara	Bush type	138 (A)	Round (1.46)	138 (A)	White	139 (D)	Prostrate	Long	Straight	Straight	Sparse	Creamish
Falguni	Bush type	N137 (B)	Ovate (1.56)	N137 (B)	White	138 (C)	Prostrate	Short	Straight	Straight	No hairs	White
Anupama	Bush type	146 (A)	Round (1.43)	146 (A)	White	139 (D)	Prostrate	Medium	Slightly curved	Slightly curved	No hairs	Dark brown
Anup	Bush type	137 (A)	Ovate (1.57)	137 (A)	White	137 (B)	Upright	Medium	Slightly curved	Slightly curved	Sparse	Dark brown
Arka Komal	Bush type	N137 (A)	Round (1.49)	N137 (A)	Deep pink to purple	139 (C)	Prostrate	Medium	Straight	Straight	Sparse	Light brown
Serengeti	Bush type	138 (A)	Ovate (1.57)	138 (A)	White	138 (B)	Upright	Long	Slightly curved	Slightly curved	No hairs	Creamish
NFL-35 (Suman)	Bush type	146 (A)	Round (1.45)	146 (A)	Deep pink to purple	139 (C)	Prostrate	Medium	Straight	Straight	Sparse	Light brown
Rani	Bush type	138 (A)	Round (1.46)	138 (A)	White	139 (D)	Prostrate	Short	Straight	Straight	No hairs	White
Bean Roshni	Bush type	146 (D)	Ovate (1.64)	146 (D)	White	137 (C)	Upright	Short	Straight	Straight	No hairs	White
Rupali	Bush type	146 (A)	Ovate (1.51)	146 (A)	White	137 (B)	Prostrate	Short	Straight	Straight	No hairs	Creamish
Fiesta	Bush type	138 (A)	Ovate (1.67)	138 (A)	White	139 (D)	Prostrate	Long	Straight	Straight	No hairs	White
Aishwarya	Bush type	137 (A)	Round (1.42)	137 (A)	White	139 (C)	Prostrate	Long	Slightly curved	Slightly curved	No hairs	White
Arka Arjun	Bush type	146 (C)	Ovate (1.52)	146 (C)	White	146 (B)	Prostrate	Short	Straight	Straight	No hairs	White
Arka Sharath	Bush type	146 (B)	Round (1.43)	146 (B)	White	138 (D)	Prostrate	Medium	Straight	Straight	No hairs	White
Harsha	Bush type	146 (A)	Round (1.40)	146 (A)	White	146 (A)	Prostrate	Medium	Slightly curved	Slightly curved	No hairs	White

Where, PGH = Plant growth habit, SP = Stem pigmentation, LS = Leaflet shape, LC = Leaf colour, FWC = Flower wing colour, PC= Pod colour, OP= Orientation of pods, PBS = Pod beak shape, PS = Pod shape, PCU = Pod curvature, PP = Pod pubescence and SC = Seed colour

Table 3. Frequency distribution, proportion and Shannon-weaver diversity index (H') of qualitative traits of 16 French bean genotypes

Characters	Morphological description	Frequency distribution		H'-index
		No. of genotypes in the group	Percent (%)	
Plant growth habit	Bush type	16	0	0
Stem pigmentation	137 (A)	2	12.50	1.98
	137 (B)	1	6.20	
	138 (A)	4	25.00	
	N 137 (A)	1	6.20	
	N 137 (B)	1	6.20	
	146 (A)	4	25.00	
	146 (B)	1	6.20	
	146 (C)	1	6.20	
	146 (D)	1	6.20	
Leaflet shape	Round	9	56.20	0.68
	Ovate	7	43.70	
Leaf colour	137 (A)	2	12.50	1.98
	137 (B)	1	6.20	
	138 (A)	4	25.00	
	N 137 (A)	1	6.20	
	N 137 (B)	1	6.20	
	146 (A)	4	25.00	
	146 (B)	1	6.20	
	146 (C)	1	6.20	
	146 (D)	1	6.20	
Flower wing colour	White	14	87.50	0.37
	Deep pink to purple	2	12.50	
Pod colour	137 (B)	3	18.70	
	137 (C)	1	6.20	
	138 (B)	1	6.20	2.00
	138 (C)	1	6.20	
	138 (D)	1	6.20	
	139 (C)	3	18.70	
	139 (D)	4	25.00	
	146 (A)	1	6.20	
	146 (B)	1	6.20	
Orientation of pods	Prostrate	13	81.20	0.48
	Upright	3	18.70	
Pod beak shape	Short	5	31.20	1.09
	Medium	6	37.50	
	Long	5	31.20	
Pod shape	Straight	10	62.50	0.66
	Slightly curved	6	37.50	
Pod curvature	Straight	10	62.50	0.66
	Slightly curved	6	37.50	
Pod pubescence	No hairs (glabrous)	12	75.00	0.56
	Sparse hair	4	25.00	
Seed Colour	White	9	56.20	1.15
	Creamish white	3	18.70	
	Light brown	2	12.50	
	Deep brown	2	12.50	
Overall mean of H'				0.96

slightly curved in the present study. 10 genotypes were categorized under straight (62.50 %) whereas 6 were grouped under slightly curved category. Kalauni et al (2019) and Kanwar et al (2019) earlier found significant variation in pod shape among common bean genotypes. Most of the varieties showed pods with 2 curvature pattern *viz*., slightly curved (62.50 %) and straight (37.50 %). Pod pubescence of genotypes varied from no hairs on the pods (75 %) to sparse hairs (25 %). All the genotypes fell in 4 colour groups regarding the trait seed colour *viz*., white (56.20 %), creamish white (18.70 %), light brown (12.50 %) and deep brown (12.50 %). Pandey et al (2011) and Kalauni et al (2019) also found significant variation in seed colour among common bean genotypes.

Biodiversity in any crop species can be summarized with two of its components *i.e.* allelic evenness and allelic richness. The richness indicates the number of genotype present in a designated area whereas evenness stands for the relative abundance of each genotype (Mondal et al 2020). The value of Shannon-Weaver diversity index (H) value varied from 0.00 for plant growth habit to 2.00 for pod colour. High Shanon-Weaver diversity index with an overall mean of 96 % was obtained, confirming the existence of diversity among the genotypes. The predominant traits that showed wider variations among the genotypes were pod colour, stem pigmentation, leaf colour, seed colour and pod beak shape. The Shannon-Wiener index values can range from 0 to 4.6. A value near 0 indicated that every species in the sample is the same and a value near 4.6 indicated the numbers of individual are evenly distributed between the French bean genotypes. A low H indicates unbalance frequency class and lack of diversity for the traits studied. A higher H' value indicates presence of variability or diversity for the trait (Hennink and Zeven 1991). Values below overall mean indicate unbalance frequency class and lack of diversity for the traits. Chatterjee (2022) also observed highly divergent qualitative traits among indigenous bush and pole type French bean germplasm collections in India.

Mean performance of genotypes: Genotypes showed highly significant variations for all the thirteen quantitative characters under study (Table 4). Wide variation in plant height was observed among French bean genotypes ranging from 34.36 cm in 'Rupali' to 46.97 cm in 'NFL-35' with a mean of 40.11 cm. Early flowering leads to early production of pods which can fetch higher market price. Days to first flowering also varied widely between 30.66 days in 'Arka Sharath' to

Table 4. Mean performance of sixteen French bean genotypes

Genotype	Plant height (cm)	Days to first flowering	Days to 50% flowering	Pod length (cm)	Pod diameter (cm)	Number of pods per plant	10 pod weight (g)	100 seed weight (g)	Number of seeds per pod	Protein content (%)	Total sugar (%)	PDI of bean anthracnose	Pod yield per plant
Malgudi	42.813	31.333	34.667	13.940	0.867	19.800	72.793	17.107	6.500	2.057	3.820	12.340	87.193
Akshara	40.180	33.667	37.333	13.267	0.693	17.000	54.620	20.197	6.300	3.737	5.430	17.083	77.787
Falguni	40.940	33.667	37.000	13.323	0.707	17.400	56.100	15.490	6.767	3.320	5.283	16.717	78.813
Anupama	41.487	32.667	36.333	13.440	0.773	18.000	59.093	24.057	6.133	2.887	5.027	14.877	79.387
Anup	38.653	34.667	38.333	13.150	0.640	14.133	47.107	22.530	5.467	4.993	6.330	18.453	72.760
Arka Komal	41.987	31.667	36.333	13.500	0.803	18.333	63.933	35.033	4.267	2.267	4.747	13.760	81.167
Serengeti	37.367	37.333	40.667	12.383	0.607	12.600	41.133	20.830	6.167	5.317	6.803	19.757	68.140
NFL-35 (Suman)	46.973	31.000	34.333	14.173	0.977	20.387	74.933	20.387	5.367	1.633	3.760	12.040	92.240
Rani	37.260	38.000	41.000	12.320	0.587	12.400	41.027	16.257	6.033	5.503	7.327	21.840	68.047
Bean Roshni	39.953	34.333	38.000	13.190	0.683	15.867	47.133	15.490	6.267	4.150	6.020	17.800	74.543
Rupali	34.360	39.333	41.333	11.840	0.577	12.200	39.513	15.337	5.333	5.600	7.630	25.397	66.050
Fiesta	40.073	34.333	37.667	13.207	0.683	16.067	47.833	16.810	6.033	4.057	5.783	17.780	76.727
Aishwarya	37.620	36.333	39.333	12.527	0.630	13.867	44.053	20.000	6.667	5.117	6.703	18.643	70.307
Arka Arjun	42.480	31.333	36.000	13.770	0.830	18.933	67.167	20.080	5.967	2.123	3.967	12.780	83.580
Arka Sharath	44.127	30.667	33.667	14.260	0.987	21.600	79.420	20.083	5.967	1.447	3.390	11.860	95.293
Harsha	35.520	40.000	43.000	11.503	0.547	11.800	38.680	20.113	5.433	5.610	7.680	26.750	61.387
Mean	40.112	34.396	37.813	13.112	0.724	16.274	54.659	19.988	5.917	3.739	5.606	17.367	77.089
CD (p=0.05)	NA	2.054	2.44	0.931	0.061	4.113	9.145	0.519	0.267	0.244	0.267	0.325	NA
C.V. (%)	12.70	3.581	3.87	4.25	5.010	15.155	10.034	1.558	2.709	3.907	2.857	1.123	18.363

40.00 days in 'Harsha' with a mean of 34.39 days. Similar trend was found for the trait days to 50 % flowering. The minimum days taken to 50 % flowering was recorded in 'Arka Sharath' (33.66 days) whereas 'Harsha' (43.00 days) was found to take maximum days for 50 % flowering. Kumar et al (2014) and Lyngdoh et al (2017) also observed similar range regarding the flowering traits. Combination of both pod length and pod diameter determines pod shape. Pod length varied widely between 11.50 cm in 'Harsha' and 14.26 cm in 'Arka Sharath'. Similarly, minimum pod diameter was observed in 'Harsha' (0.54 cm) and the maximum was observed in 'Arka Sharath' (0.98 cm). Kanwar et al (2017) at Himachal Pradesh and Razvi et al (2017) at Jammu and Kashmir also found similar range among genotypes regarding pod length and diameter. Higher number of pods per plant leads to more pod yield per plant. Number of pods varied widely among genotypes ranging from 11.80 to 21.60. The maximum number of pods was produced by 'Arka Sharath' (21.60) followed by 'NFL-35' (20.38) whereas the lowest was recorded in 'Harsha' (11.80). 10 pod weight varied between 38.68 g in 'Harsha' and 79.42 g in 'Arka Sharath', the mean being 54.65 g. Jhanavi et al (2018) reported similar range regarding these traits among the genotypes from a study conducted at College of Horticulture, Bagalkot, Karnataka.

In case of the trait 100 seed weight, 'Rupali' exhibited minimum value (15.33 g) whereas 'Arka Komal' showed maximum value (35.03 g). Number of seeds per pod ranged from 4.26 to 6.76 with a mean value of 5.91. The minimum and maximum value regarding this trait was exhibited by the genotypes 'Arka Komal' (4.26) and 'Falguni' (6.76 g) respectively. Prakash and Ram (2014) and Razvi et al (2017) reported similar ranges regarding these two traits among the genotypes they studied. Regarding the trait protein content of green pod, minimum and maximum value was observed in 'Arka Sharath' (1.44 %) and 'Harsha' (5.61 %) respectively with a mean value of 3.73 %. The mean value of the trait total sugar content of green pod was 5.60 %, the minimum being 'Arka Sharath' (3.39 %) and the maximum in 'Harsha' (7.68 %). The range of total sugar content of green pod in the present study is in line with the findings of Prakash and Ram (2014).

Genetic variability and heritability: The genotypes exhibited highly significant differences for all the characters under study (Table 5) which clearly supports the justification of studying genetic variability of different characters employing these genotypes. Coefficient of variation was widely different ranging from minimum of 1.12 to maximum of 18.36 (Table 4). In the present investigation, the phenotypic coefficient of variations was slightly higher than the corresponding genotypic coefficient of variations for all the characters studied (Table 6) which indicated that the apparent variation was not only due to genotypes but also due to the influence of environment in the expression of the traits. However, the influence of environment for the expression of characters was not very high suggesting appreciable genotypic worth for all the characters. Such inference could also be drawn from the magnitude of low to moderate coefficient of variation for the characters. Hence, the characters could be improved following different phenotypic selections like directional, disruptive and stabilized selections (Mondal et al 2020).

Phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were categorized as low (0-10%), moderate (10-20%) and high (>20%) (Sivasubramanian and Madhavamenon 1973). Accordingly, very high PCV and GCV values were recorded for protein content of green pod (PCV 40.69; GCV 40.50) which indicated the highest magnitude of variability for this character. High magnitude of GCV and PCV, respectively were recorded for 10 pod weight, PDI of bean anthracnose, total sugar content of green pods, 100 seed weight and pod yield per plant. Moderate PCV and GCV were registered for the trait pod diameter. Whereas, the trait number of pods per plant had high PCV value and moderate GCV value. Similar findings were previously reported by earlier researchers like Kumar et al (2014), Verma et al (2014), Topwal and Gaur (2016), Lyngdoh et al (2017), Jhanavi et al (2018), Ramandeep et al (2018) and Yumkhaibam et al (2019). High

Table 5. ANOVA for thirteen quantitative characters of French bean

Source of variation	Mean sum of square		
	Replication	Treatments	Error
DF	2	15	30
Plant height (cm)	593.37	481.20**	778.89
Days to first flowering	3.16	410.81**	45.50
Days to 50% flowering	0.87	323.97**	64.45
Pod length (cm)	0.92	28.83**	9.34
Pod diameter (cm)	0.001	0.83**	0.03
Number of pods per plant	30.02	448.52**	182.49
10 pod weight (g)	118.22	8230.35**	902.35
100 seed weight (g)	0.42	1034.23**	2.90
Number of seeds per pod	0.002	17.51**	0.77
Protein content of green pod (%)	0.10	103.51**	0.63
Total sugar content of green pod (%)	0.009	90.38**	0.76
PDI of bean anthracnose (%)	0.67	918.39**	1.14
Pod yield per plant (g)	99.91	3996.51**	6011.62

** Significant at 0.01 level of probability

to moderate magnitude of GCV and PCV generally indicated ample scope for improvement through selection. The present findings clearly indicated the worth of the traits namely protein content of green pod, 10 pod weight, PDI of bean anthracnose, total sugar content of green pods, 100 seed weight, pod yield per plant, pod diameter and number of pods per plant for the study of genetic variability in French bean.

Genotypic coefficients of variation do not estimate the variations that are heritable hence, estimation of heritability is absolutely necessary (Falconer 1960). Heritability is classified as low (below 30 %), medium (30-60 %) and high (above 60 %) (Johnson et al 1955). Among the characters studied, high heritability estimate was recorded for days to first flowering (85.04 %), days to 50 % flowering, pod length, pod diameter, number of pods per plant, 10 pod weight, 100 seed weight, number of seeds per pod, protein content of green pod, total sugar content of green pod, PDI of bean anthracnose and pod yield per plant. The trait plant height only showed low heritability (Table 6). High heritability indicates less environmental influence in the observed variation (Songsri et al 2008) which suggested that selection based on phenotypic expression could be relied upon as

Table 6. Mean, range and estimates of genetic parameters of sixteen French bean genotypes

Character	Mean	Range	GCV*(%)	PCV*(%)	GCV:PCV	h² in broad sense (%)	Genetic advance as % of mean
Plant height (cm)	40.112	34.360-46.973	3.559	13.192	26.984	7.280	1.978
Days to first flowering	34.396	30.666-40.000	8.537	9.258	92.219	85.041	16.219
Days to 50% flowering	37.813	33.666-43.000	3.876	6.733	57.566	75.117	12.022
Pod length (cm)	13.112	11.503-14.260	5.589	7.025	79.558	63.303	9.159
Pod diameter (cm)	0.724	0.546-0.986	18.616	19.279	96.563	93.254	37.03
Number of pods per plant	16.274	11.800-21.600	17.313	23.009	75.245	60.623	26.837
10 pod weight (g)	54.659	38.680-79.420	24.054	26.063	92.292	85.187	45.733
100 seed weight (g)	19.988	15.336-35.033	23.968	24.019	99.789	99.580	49.271
Number of seeds per pod	5.917	4.266-6.766	10.427	10.773	96.788	93.682	20.790
Protein content of green pod (%)	3.739	1.446-5.610	40.506	40.694	99.538	99.080	83.058
Total sugar content of green pod (%)	5.606	3.390-7.680	25.225	25.387	99.364	98.733	51.634
PDI of bean anthracnose (%)	17.367	11.860-26.750	26.004	26.028	99.906	99.812	53.518
Pod yield per plant (g)	77.089	61.386-95.293	20.086	21.345	94.10	71.423	34.432

GCV = Genotypic coefficient of variation; PCV = Phenotypic coefficient of variation

Table 7. Phenotypic path analysis for thirteen characters of sixteen French bean genotypes

Character	PH	DFF	D50F	PL	PD	NPPP	10PW	100SW	NSPP	PC	TS	PDIA	Correlation with FYPP at phenotypic level
PH	-0.049	0.048	0.405	-0.139	0.356	-0.185	0.228	0.008	0.001	0.141	-0.458	-0.004	0.353*
DFF	0.025	-0.097	-0.716	0.293	-0.562	0.331	-0.345	-0.017	0.001	-0.213	0.727	0.007	-0.568**
D50F	0.024	-0.084	-0.832	0.314	-0.562	0.327	-0.334	-0.011	-0.009	-0.205	0.696	0.006	-0.669**
PL	-0.020	0.081	0.747	0.538	-0.350	-0.284	0.316	0.010	0.016	0.187	-0.663	-0.006	0.571**
PD	-0.027	0.083	0.708	-0.285	0.660	-0.336	0.379	0.013	-0.011	0.223	-0.744	-0.006	0.657**
NPPP	-0.021	0.076	0.637	-0.233	-0.426	0.520	0.316	0.011	0.004	0.198	-0.642	-0.006	0.432**
10PW	-0.027	0.081	0.670	-0.267	0.603	-0.325	0.415	0.014	-0.010	0.219	-0.728	-0.006	0.641**
100SW	-0.007	0.029	0.162	-0.062	0.152	-0.082	0.105	0.056	-0.121	0.073	-0.193	-0.002	0.110
NSPP	0.000	-0.001	0.039	-0.031	-0.040	-0.010	-0.023	-0.037	0.182	-0.019	-0.018	-0.001	0.043
PC	0.029	-0.087	-0.716	0.275	-0.619	0.355	-0.383	-0.017	0.014	-0.238	0.776	0.006	-0.604**
TS	0.028	-0.089	-0.730	0.293	-0.619	0.345	-0.381	-0.014	0.793	-0.233	-0.004	0.007	-0.603**
PDIA	0.028	-0.091	-0.733	0.297	-0.584	0.337	-0.357	0.007	-0.014	-0.219	0.755	-0.018	-0.590**

Residual effect = 0.0443, Direct effect = Bold diagonals.
Where, PH =Plant height; DFF= Days to first flowering; D50F= Days to 50% flowering; PL=Pod length (cm); PD=Pod diameter (cm); NPPP =Number of pods per plant; 10 PD= 10 Pod Weight(g); 100 SW= 100 seed weight (g); NSPP= Number of seeds per pod; PC= Protein content of green pod (%); TS= Total Sugar content of green pod (%); PDIA= PDI of anthracnose (%); PYPP= Pod yield per plant (g)

there was major role of genetic constitution in the expression of these characters. At the same time, heritability value alone cannot provide information on amount of genetic progress that would result from selection of best individuals. High heritability coupled with high genetic advance as per cent of mean was observed for pod diameter, number of pods per plant, 10 pod weight, 100 seed weight, number of seeds per pod, protein content of green pod, total sugar content of green pod, PDI of bean anthracnose and pod yield per plant.

Selection indices: Among the yield component traits, pod diameter (0.660) showed high positive direct effects on pod yield per plant followed by pod length, number of pods per plant and 10 pod weight (Table 7). High and positive direct effect on green pod yield per plant through pod diameter, pod length, number of pods per plant and 10 pod weight was earlier reported by earlier researchers namely Ghimire and Mondal (2019), Noopur et al (2018), Verma and Naidu (2018), Kalauni and Dhakal (2020) and Elias et al (2021). Other traits like number of seeds per pod and 100 seed weight expressed low positive direct effects on pod yield per plant. The indirect effects via other characters were negligible. Hence, direct selection through pod diameter, pod length, number of pods per plant and 10 pod weight could be beneficial for yield improvement of French bean. Some other characters like plant height, days to first flowering, days to 50 % flowering, protein content of green pod, total sugar content of green pod and PDI of bean anthracnose showed direct negative effects on pod yield per plant. Residual effect of the path analysis was very low (0.044) suggesting the inclusion of maximum pod yield determining characters (66 %) in the present study.

CONCLUSION

The present study illustrated significant variation among genotypes for both qualitative and quantitative traits. The overall mean of Shannon-Wiener diversity index (H) value of 0.96 amply suggest the existence of diversity among the genotypes under study. Pod diameter, number of pods per plant, 10 pod weight, 100 seed weight, number of seeds per pod, protein content of green pod, total sugar content of green pod, PDI of bean anthracnose and pod yield per plant exhibited high heritability in conjunction with high genetic advance which suggests that the characters concerned are conditioned by additive gene action and therefore, these characters would be more reliable for effective selection. The maximum positive direct effects were exerted by pod diameter, pod length, number of pods per plant and 10 pod weight on green pod yield per plant. The genotypes 'Arka Sharath', 'NFL-35' and 'Harsha' were found most promising in respect to green pod yield per plant and tolerance to bean anthracnose disease. The information generated through this study will help the breeders to develop high yielding and disease resistant varieties of French bean in future.

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Effect of Preharvest Fruit Bagging on Physical Parameters of different Guava Cultivars in Rainy Season Crop

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***Abstract*:** The present investigation was carried out to evaluate the effect of different bagging materials on the physical parameters of fruits from various guava cultivars *viz*. Hisar Safeda, Hisar Surkha, Allahabad Safeda and Shweta. The fruits were bagged immediately after fruit set with various coloured paper, polythene and cloth bags., the fruits bagged with blue polythene exhibited the maximum fruit weight, fruit length, fruit width and pulp weight as compared to control in fruits of Shweta. However, maximum specific gravity was observed in fruits of Hisar Safeda and Hisar Surkha as compared to the minimum in Shweta fruits. Hence, the fruits bagged with blue polythene, cotton cloth and green polythene were found promising in enhancing the physical parameters of various guava cultivars taken in the study.

***Keywords*:** Ascorbic acid, Cloth bags, Phytonutrients, Polythene bags, Hisar Safeda

Guava (*Psidium guajava* L.), a member of family *Myrtaceae*, widely grown in the tropical and subtropical regions of the world. Due to its wider adaptability in diverse agroclimatic regions, low cultivation cost, prolific bearing and being highly remunerative. Plants growth affected by many biotic and abiotic factors under field conditions . Fruits obtained during rainy season are of poor quality and highly infested by fruit fly (*Bactrocera correcta* Bezzi) along with the infection of anthracnose (*Colletotrichum gloeosporioides* Penz.) disease . Additionally, birds also damage the fruits which leads to heavy crop losses. To control fruit fly, practices such as, use pheromone traps, poison food traps botanicals, chemical insecticides, is very common among the growers. However, these practices are cumbersome, pocket draining and also imparts residue problems on fruits which is a major concern for the consumers. Therefore, the fruit bagging has appeared as a potential approach in current times. Growers from Japan, Australia, and China are commercially employing this practice for the production of apple, peach, pear, grape, loquat, etc. for the enhanced yields and improved quality of the fruits . During fruit bagging, individual fruit or fruit bunch is covered with a bag (such as, polythene bag, cloth bag, paper bags etc.) on the tree at a specific stage for a specific period. Bagging not only improves the visual appeal of fruits, however, also changes the microenvironment inside a bag and also acts as a physical barrier between fruit and environment, reducing the incidence of pests, diseases, physiological disorders and abrasions on fruits . Hence, the present study was conducted to observe the impact of preharvest fruit bagging on the rainy season crop with four guava cultivars with an aim to screen various bagging material to attain higher yields.

MATERIAL AND METHODS

Experimental site: The present study was carried out at the farms of Guava Demonstration Centre, Bhuna, Fatehabad, Haryana situated at 29° 32' latitude, 75° 42' longitudes and 222m above mean sea level. This area particularly represents a wide variation in average maximum and minimum temperatures. The temperature varied from 40 °C to 48 °C during summer to as low as to freezing point accompanied with chilling frost in winters. The approximate average rainfall was 450 mm, most of which received mainly during Southwest monsoon (July to September), while few showers also occur during December to February (western disturbances). The physiochemical analysis of fruits was done at CCS Haryana Agricultural University, Hisar.

Experimental details: The well-trained trees of 4 different cultivars *viz.* Hisar Safeda, Hisar Surkha, Allahabad Safeda and Shweta were selected for the experiment. All the selected trees were of same size and vigour with an age of 6 to 7 years old. The planting geometry was of 3 x 6 m on raised

bunds with drip irrigation facilities. Before experimental proceedings, selected trees were pruned and subjected to the recommended cultural practices such as, irrigation, fertilization, weeding, insect pest and disease management. fifteen uniform sized fruits were bagged immediately after fruit set each on three plants (replications) with different material as per treatment schedule (Table 1). Five fruits from each plant, such as,15 fruits (from 3 replications) were harvested from each cultivar for each treatment and subsequently analysed for different parameters as mentioned in next section. Harvesting time of fruits among the treatments was same, however, varied among cultivars. Treatments details are given in Table 1.

Evaluation of physical parameters: To assess the fruit weight (g), each selected fruit was weighed and the mean weight of fruits was calculated and expressed in gram. To measure fruit length/width (cm), the length and width were measured from the stalk end to the calyx end of fruits. Specific gravity of fruit was determined by dividing the weight of the fruits in the air to the volume of the fruits as obtained by water displacement method such as, rise in water level in the cylinder. Formula applied for calculation of specific gravity is given below:

$$\text{Specific gravity (g cm}^{-3}\text{)} = \frac{\text{Weight of fruit (g)}}{\text{Volume of water displaced by fruit (ml)}}$$

To measure the fruit weight, the fruit was peeled off, seeds from the pulp were removed and weighed balance for measuring pulp weight. Pulp weight was calculated by the following formula:

Pulp weight (g) = Initial weight of the fruit (g) – [Weight of the peel (g) + weight of the seeds]

Statistical analysis: The data was statistically analysed in Randomized Block Design using SPSS software (IBM, SPSS Inc., USA).

RESULTS AND DISCUSSION

Fruit weight: The maximum fruit weight (114.03 g) was in fruits wrapped with blue polythene bags, which was statistically at par with fruits bagged in cotton cloth and green polythene while control had the minimum weight (91.01 g), which was statistically at par with fruit bagged in white polythene and pink polythene (abTable 2). Among the cultivars, fruit weight was maximum (122.14 g) in fruits of Shweta, while the minimum (91.12 g) was in Hisar Surkha fruits, which was statistically at par with fruits of Allahabad Safeda. Increase in fruit weight might be due to the conducive effects of bagging such as, increased relative humidity and reduced water loss from the fruits . The physical protection of fruit from ultra violet rays as provided by bags results in the increased cell division and proper availability of photosynthates to the developing fruits might be a cause of increased fruit weight. However, increased weight of Shweta cultivar is owed to its genetic characteristics. These findings were also in a close agreement with and in bagged guava fruits.

Fruit length: The bagging significantly affected the fruit length and the maximum (6.91 cm) was in fruits bagged with blue polythene, which was statistically at par with fruits wrapped in cotton cloth and green polythene bags. The minimum fruit length (5.71 cm) was in control, which was statistically at par with fruit bagged with pink polythene. Among the cultivars, fruits of Shweta had the maximum fruit length (7.07 cm), while the minimum (5.95 cm) was in fruits of Hisar Surkha. Variability among the bag type (differences in the transmittance level and absorption in different spectral bands by different bag materials) plays a significant role in modification of microclimate in bags which might be a reason for increased fruit size also reported the maximum fruit weight in bagged guava fruits,

Fruit width: Fruit width was also affected significantly with the bagging treatments. Fruits bagged with blue polythene had the maximum fruit width (7.34 cm), which was statistically at par with fruits bagged in cotton cloth and green polythene, as compared to the minimum width (6.13 cm) observed in unbagged fruits, which was statistically at par with fruit wrapped in pink polythene bags. Among the cultivars, the maximum fruit width (7.46 cm) was in fruits of Shweta as compared to the minimum (6.38 cm) in Hisar Surkha fruits (Table 2). This might be due to different light intensity and temperature inside the bag developed due to colour and material of the bags resulted in increased weight and diameter by rapid cell division and expansion. Similar results were obtained by in bagged guava.

Pulp weight: The maximum pulp weight (98.60 g) was in fruits bagged with blue polythene, which was statistically at par with fruits wrapped in cotton cloth and green polythene bags. Control (unbagged fruits) had the minimum pulp weight (77.15 g), which was statistically at par with fruits bagged in pink polythene and white polythene. Cultivars have significant differences and the maximum pulp weight (103.92 g) was in fruits of Shweta as compared to the minimum (78.42 g) in fruits of Hisar Surkha, which was statistically at par with fruits of Allahabad Safeda. Pulp weight of fruits is correlated to the fruit weight and size. Bagging influences the light movement, provides optimum intensity and better quality light which had favorable effect on development of fruit pulp. The findings of present investigation corroborated with the findings of.

Specific gravity (g/cm^3): Treatment**s** does not significantly

Table 1. Effect of pre-harvest fruit bagging on fruit weight (g), length (cm) and width (cm) of different guava cultivars in rainy season crop (2019-20)

Sr. No.	Treatments	Fruit weight (g)					Fruit length (cm)					Fruit width (cm)				
		Hisar Safeda	Hisar Surkha	Allahabad Safeda	Shweta	Mean	Hisar Safeda	Hisar Surkha	Allahabad Safeda	Shweta	Mean	Hisar Safeda	Hisar Surkha	Allahabad Safeda	Shweta	Mean
T_1	White paper bag	93.78	84.45	89.05	119.48	96.69	5.76	5.58	5.85	6.97	6.04	6.16	6.01	6.33	7.36	6.47
T_2	Red paper bag	104.30	92.56	95.78	124.90	104.39	6.32	6.04	6.18	7.29	6.46	6.72	6.47	6.66	7.68	6.88
T_3	Yellow paper bag	102.15	90.12	94.06	125.23	102.89	6.28	5.88	6.07	7.35	6.40	6.68	6.31	6.55	7.74	6.82
T_4	Green paper bag	106.12	94.56	96.47	128.57	106.43	6.43	6.17	6.27	7.51	6.60	6.83	6.60	6.75	7.90	7.02
T_5	Blue paper bag	109.63	97.10	98.23	122.12	106.77	6.65	6.32	6.46	7.16	6.65	7.05	6.75	6.94	7.55	7.07
T_6	Brown paper bag	98.29	83.93	86.96	118.81	97.00	6.02	5.52	5.68	6.78	6.00	6.42	5.95	6.16	7.17	6.43
T_7	Newspaper bag	96.41	86.21	90.67	113.72	96.75	5.97	5.65	5.91	6.55	6.02	6.37	6.08	6.39	6.94	6.45
T_8	Transparent polythene bag	98.96	91.42	87.58	116.23	98.55	6.11	5.95	5.76	6.71	6.13	6.51	6.38	6.24	7.10	6.56
T_9	White polythene bag	95.63	87.34	85.36	115.32	95.91	5.89	5.71	5.59	6.62	5.95	6.29	6.14	6.07	7.01	6.38
T_{10}	Pink polythene bag	91.80	82.01	83.23	111.65	92.17	5.69	5.46	5.53	6.47	5.79	6.09	5.89	6.01	6.86	6.21
T_{11}	Yellow polythene bag	107.58	96.21	97.39	127.77	107.24	6.57	6.27	6.35	7.42	6.65	6.97	6.70	6.83	7.81	7.08
T_{12}	Green polythene bag	111.37	100.60	100.61	133.41	111.50	6.75	6.43	6.53	7.59	6.83	7.15	6.86	7.01	7.98	7.25
T_{13}	Blue polythene bag	114.21	101.97	104.70	135.24	114.03	6.83	6.54	6.61	7.67	6.91	7.23	6.97	7.09	8.06	7.34
T_{14}	Cotton cloth bag	113.76	99.13	102.45	131.10	111.61	6.78	6.48	6.58	7.63	6.87	7.18	6.91	7.06	8.02	7.29
T_{15}	Muslin cloth bag	100.20	89.76	92.89	120.59	100.86	6.19	5.76	5.99	7.08	6.26	6.59	6.19	6.47	7.47	6.68
T_{16}	Control (unbagged)	90.34	80.62	82.92	110.15	91.01	5.63	5.38	5.45	6.36	5.71	6.03	5.81	5.93	6.75	6.13
	Treatment Mean	102.16	91.12	93.02	122.14		6.24	5.95	6.05	7.07		6.64	6.38	6.53	7.46	
C.D. (p=0.05)		Treatments (T) = 4.92, Cultivars (C) = 2.46, T x C = NS					Treatments (T) = 0.13, Cultivars (C) = 0.07, T x C = NS					Treatments (T) = 0.14, Cultivars (C) = 0.07, T x C = NS				

Table 2. Effect of pre-harvest fruit bagging on pulp weight (g), specific gravity and organoleptic score of different guava cultivars in rainy season crop (2019-20)

Sr. No.	Pulp weight (g)					Specific gravity				
	Hisar Safeda	Hisar Surkha	Allahabad Safeda	Shweta	Mean	Hisar Safeda	Hisar Surkha	Allahabad Safeda	Shweta	Mean
T_1	79.49	72.05	75.79	101.28	82.15	0.98	0.97	0.96	0.95	0.96
T_2	88.43	79.40	82.16	105.89	88.97	0.99	0.99	0.98	0.96	0.98
T_3	86.60	77.30	80.68	106.17	87.69	0.99	0.98	0.97	0.97	0.98
T_4	89.97	81.11	82.75	109.00	90.71	0.99	0.99	0.98	0.97	0.98
T_5	94.28	84.48	85.46	105.02	92.31	1.00	1.00	0.98	0.96	0.98
T_6	83.33	72.00	74.59	100.73	82.66	1.00	0.97	0.96	0.94	0.97
T_7	81.29	73.55	77.36	95.89	82.02	0.98	0.98	0.97	0.93	0.96
T_8	83.90	78.42	75.13	98.54	84.00	0.99	0.99	0.96	0.95	0.97
T_9	80.64	74.52	72.83	97.24	81.31	0.98	0.98	0.95	0.94	0.96
T_{10}	77.41	69.97	71.01	94.14	78.13	0.98	0.97	0.95	0.93	0.96
T_{11}	92.52	83.70	84.73	109.90	92.71	0.99	0.99	0.98	0.97	0.98
T_{12}	95.78	87.52	87.53	114.73	96.39	1.00	1.00	0.99	0.98	0.99
T_{13}	98.22	88.71	91.14	116.31	98.60	1.02	1.02	0.99	0.98	1.00
T_{14}	97.83	86.24	89.13	112.75	96.49	1.02	1.02	0.99	0.98	1.00
T_{15}	84.95	77.00	79.68	102.24	85.97	0.99	0.98	0.97	0.95	0.97
T_{16}	76.17	68.78	70.75	92.88	77.15	0.98	0.97	0.95	0.93	0.96
Treatment mean	86.93	78.42	80.05	103.92		0.99	0.99	0.97	0.96	
CD (p=0.05)	Treatments (T) = 4.20, Cultivars (C) = 2.10, T x C = NS					Treatments (T) = NS, Cultivars (C) = 0.02, T x C = NS				

See Table 1 for treatment details

influence the specific gravity as compared to control. The specific gravity among the cultivars was maximum (0.99) in fruits of Hisar Safeda and Hisar Surkha, which was statistically at par with specific gravity of Allahabad Safeda fruits, while the minimum specific gravity (0.96) was in Shweta fruits. This might be due to more compact tissues developed under the bagging and hence there was a minimal increase in volume of fruits as compared to fruit weight resulting in the higher specific gravity. Similar results were obtained by in bagged guava.

CONCLUSION

The bagging with blue polythene, cotton cloth, and green polythene shows promising results for enhancing fruit length, weight, width, and pulp weight. Among the cultivars, Shweta fruits bagged with blue polythene, cotton cloth, and green polythene showed the most significant improvement in most fruit physical parameters. Overall, this study highlights the potential of preharvest bagging at the right developmental stage as a useful approach for improving both the quantity and quality of guava fruits.

AUTHOR CONTRIBUTION

MB, RKG: conceptualization, methodology, investigation, writing original draft preparation. AK, CV: reviewing and editing. B, MK, AK: reviewing the final draft and editing. All authors contributed to the article and approved the submitted version.

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Physiological and Pathological Variability of *Botrytis cinerea* Causing Botrytis Grey Mould of Himachal Pradesh in India

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***Abstract*:** Botrytis grey mould (BGM) is observed in the fields and one of the most important plant pathogen because of the detrimental ramification on the ornamental flowers and vegetables every year in Himachal Pradesh, India. The focus of this work is to study the physiological and pathological variability was studies in fifteen isolates of *Botrytis cinerea* causing botrytis grey mould of gladiolus collected from different agro climatic area of Himachal Pradesh. This research aimed to explore the effect of different factors which affects the growth of *Botrytis cinerea*. Moreover, to find out the pathological variability among the isolates. The optimum temperature for the best mycelial growth of *B. cinerea* were 20 ºC and thereafter it decreased gradually up to 30ºC. The production of sclerotia was affected by the distinct temperature regimes and was maximum at temperature 10°C and 15°C. Furthermore, also observed that the glucose (fructose) and nitrogen (asparagines) sources were to enhance the mycelial growth of *B. cinerea.* Maximum disease severity was shown by KBC-16 (58.78%) on Jester cultivar of gladiolus whereas, minimum severity was given by KBC-5 (34.47%). Under in vitro conditions, it is observed that on fifth day the flowers were completely deteriorated with the fungal growth.

***Keywords*:** Botrytis grey mould, *Botrytis cinerea* and Himachal Pradesh

Gladiolus *(Gladiolus grandiflorus* L.) belonging to the family Iridaceae and is most commercial cultivated cut flower in India (Bika et al 2020, Bi et al 2022). Botrytis grey mould (BGM) *Botrytis cinerea* is one of the major and destructive disease of gladiolus and possess a major constraint to production of flower, cormels and corms of gladiolus. In mostly, the approximately 30 recognized *Botrytis* species with various trophic lifestyles and is placed among the top ten most dominant fungal pathogens (Hurtado-Bautista et al 2021). It is also known as soft corm rot, core rot, grey mould and leaf spot (Schuster 2004, Tesfaye and Kapoor 2004, Sultana et al 2019).Botrytis grey mould is found worldwide and causes diseases in different flowers, vegetables crops and fruits (Boff 2001, Hosen 2011, Carisse 2016, Wang et al 2022). Variability in fungi is noticed in morphology (Chardonnet et al 2000) and pathogenicity (Aboelghar et al 2019). The spores of the *B. cinerea* is found highly in numbers and comes out from the infected tissues (Jarvis 1962, Dewey and Grant- Downton 2016). *B. cinerea* mainly enters the host via wounds or natural openings (Holz et al 2007). It can actively promote susceptibility in the host by inducing different virulence factors (Choquer et al 2007, Nakajima and Akutsu 2014, Petrasch et al 2019). *B. cinerea* causes lysis of plant cell and facilitates penetration by loosens host wall (Blanco-Ulate et al 2016). The grey mould agents are one of the most studied models (Veloso and Van Kan 2018, Fekete et al 2011). *B. cinerea* is not specific and its virulence varies from host to host (Derckel et al 1999, Mirzaei et al 2009, Romanazzi and Feliziani 2014). *B. cinerea* rated as second most important fungal pathogen widely adopted as molecular model organism (Dean et al 2012). Strains of *B. cinerea* may start accumulate mutations in its genetic material that allow it to survive in different environment, resulting in damages to various crops worldwide (Harper et al 2022). In this study, our objective was to characterize the physiological and pathological variability in between fifteen *B. cinerea* isolates that were isolated from gladiolus on the radial colony growth on different temperature regimes and colony morphology, sporulation and sclerotia production of *B. cinerea* isolates grown on liquid growth media.

MATERIAL AND METHODS

Collection, isolation and preservation of *B. cinerea*: The fifteen isolates of *Botrytis cinerea* were isolated from the different major gladiolus growing districts of Himachal Pradesh namely Solan, Shimla, Sirmour, Mandi and Kullu. These *B. cinerea* isolates were isolated using single spore isolation technique and inoculated on potato dextrose agar (PDA) medium at 20± 0.5ºC (Mian 1995). Fifteen single spore isolates were produced from the diseased gladiolus

sample and designated as BC-1. B C-6, BC-8, KBC-10, KBC-1, KBC-14, KBC-13, KBC-16, KBC-5, KBC-15, KBC-9, BC-5, KBC-2, KBC-3 and KBC-11. The pure cultures of *B. cinerea* isolates were maintained on PDA slants and stored in 15% glycerol stocks at -20°C.

Physiological variability: Radial colony growth *B. cinerea* isolates were determined by inoculation of a 5 mm diameter portion of agar colonized with mycelium from 2-day-old cultures placed on center of a PDA plate and grown in the dark at room temperature (20°C). The inoculated Petri plates were incubated at different temperature ranging between 10, 15, 20, 25 and 30°C following completely randomized design (CRD) comprising of three replications. The observation on growth character, sporulation and other characters were recorded after 7 days of inoculation.

Effect of liquid nutrient media (carbon and nitrogen sources) on growth of isolates: Czapeck's Dox broth medium was used as basal medium for identifying the best carbon and nitrogen sources for growth characters, sporulation and sclerotial formation of different isolates of *Botrytis cinerea*. The carbon and nitrogen sources already present in the basal medium was substituted with galactose, dextrose, fructose, raffinose, ammonium nitrate, glutamine, potassium nitrate and asparagine with equal amount as per liter as obtained from sucrose and sodium nitrate. No carbon and nitrogen sources were added to control. Dry mycelia weight (mg), sporulation, and spore size were measured after 20 days of inoculation. The mycelial mats of isolates were filtered through pre-weighed Watman No.1 filter paper, and washed thoroughly with distilled water, and dried in a hot air oven at 60°C for 24 hour, cooled in a desiccator and weighed. The statistical analyses were performed to accomplish the best sources of carbon and nitrogen for the test pathogen. The sclerotial distribution of all the isolates were recorded on the 20th day after inoculation in a PDA medium, and classified based on the types of distribution suggested by Tanovic et al (2009), with some modifications (Table 1).

Pathological variability: The virulence of the *Botrytis cinerea* isolates were tested on the most demanding and commercial cultivars of gladiolus viz., Jester, Peter Pears, Rose Prosperity and White Prosperity were selected for artificial inoculation. Isolates considered for pathogenicity study were collected from different locations of gladiolus growing areas of different districts of Himachal Pradesh. The test on aggressiveness was conducted according to Abdel Wahab (2015). Healthy spikes of gladiolus used in the pathogenicity assessment were collected from three months old plants and inoculated uniformly with fungus spore suspension at the concentration 10^6 CFU/ml. Ten ml of the spore suspension was applied for each treatment using a hand atomizer. After inoculation, plants were covered with polyethylene cover for 48 h to provide high moisture, then polyethylene opened partially, after 72 h the polyethylene was removed. Plants were kept under normal conditions until the appearance of the symptoms. Disease severity was noticed up to five days from inoculation (Fig. 3). Uninoculated spikes of each cultivars served as control treatment. The disease appearance was also noticed up to five days to assess the virulence among the isolates. The per cent disease index (PDI) was assessed using the following rating scale and was calculated as per Mc Kinney (1923).

Table 1. Disease rating scale for calculating per cent disease incidence for Botrytis grey mould

Ratings	Infected spikes parts
0	No infection
1	< 1/4 area of flower infected
2	>¼ to ½ area of flower infected
3	>½ to ¾ area of flower infected
4	>3/4 area of flower infected

RESULTS AND DISCUSSION

Physiological variability: The radial mycelial growth at 10 °C was reduced as compared to 15 and 20°C and gradually decreased up to 30°C (Table 2). At 20°C highest colony diameter was shown by all the isolates except KBC-3 (82.0 mm) followed by KBC-2 (84.0 mm). The maximum sporulation given by all *B.cinerea* isolates at 25°C followed by 20 °C. The size of conidia was increased with increase in temperature (Table 4). The maximum spore size was observed in KBC-16 (9.00 x 6.30 µm) followed by BC-1 (9.10 x 4.48 µm) at 25°C. At 20°C maximum spore size was recorded again in KBC-16 (8.79 x 5.66 µm) followed by KBC-14 and BC-1. The effects of five temperature regimes were observed same on colony colour and texture in all the different *Botrytis* isolates except KBC-9 which showed dark grey color and cottony texture at 10, 15 and 20°C, while the same isolate observed off white colour and fluffy texture at 25°C and 30°C (Table 3). The production of sclerotia was maximum at temperature 10°C and 15°C, respectively whereas minimum production of sclerotia occurred at 25°C temperature. No sclerotia were formed at 30°C in all the isolates tested (Table 4). Isolates of *B. cinerea* showed good colony growth at the wide range of temperature (15-25°C). The least growth was recorded at 10 and 25°C. The optimum temperature for the growth of *B. cinerea* isolates was 20°C (Pande et al 2010; Fernandez et al 2014, Sehajpal and Singh 2014). The distribution of sclerotia also varied among *B.*

cinerea isolates which included centrally placed large sclerotia, arranged in concentric rings, towards the periphery and sclerotia arranged irregularly (Kuzmanovska et al 2012, Sehajpal and Singh 2014, Kumari et al 2014, Mang et al 2020).

Effect of liquid nutrient media (carbon and nitrogen sources) on growth of isolates: The effect of carbon (galactose, dextrose, fructose and raffinose) and nitrogen (ammonium nitrate, glutamine, potassium nitrate and asparagine) sources on mycelial growth of *Botrytis cinerea* was studied under *in vitro* conditions (Table 5). Maximum dry weight (660 and 560 mg) was shown by KBC-10 with respect to fructose and raffinose (carbon sources) followed by KBC-9 (640 and 580 mg). Though maximum conidial size in KBC-16 was recorded in fructose (11.66 x 6.01 µm) followed by raffinose (11.33 x 5.99 µm) while minimum conidial size (4.99 x 2.02 µm) was obtained by BC-6 in raffinose. However, excellent sporulation was observed in fructose, raffinose and galactose by BC-1, KBC-10, KBC-16 and KBC-9 isolates collected from Jhiri (Kullu), Rajgarh (Sirmour), Sundernagar (Mandi) and Namhole (Bilaspur).

During nitrogen sources estimation maximum dry weight i.e. 610 mg (asparaine) and 540mg (potassium nitrate) was shown by BC-8. While no mycelial growth was observed in ammonium nitrate and glutamine by KBC-1 isolate. Maximum spore size (12.11 x5.66 µm) was observed in KBC-9 supplemented with asparagine followed by KBC-10 (10.45 x 4.99 µm) in same nitrogen source. However the excellent sporulation was found in all nitrogen sources by four isolates such as BC-1, KBC-10 and KBC-9. Hence the fructose and asparagines were reported to enhance the mycelial growth of *B. cinerea.* During the estimation of carbon and nitrogen sources, carbon (fructose and raffinose) in comparison to nitrogen (asparagine) sources was found to be best as it increased the dry mycelial weight (660 and 560 mg), conidial size (11.66 x 6.01 and 11.33 x 5.99 µm), excellent sporulation and sclerotia production in isolates BC-1, KBC-10, KBC-16 and KBC-9. However all the isolates showed more growth in carbon sources than nitrogen (Table 6). The maximal increment in dry weight (610 mg) was observed in BC-8, spore size (12.11 x 5.66 µm) in KBC-9, excellent sporulation and sclerotia production in medium supplemented with asparagine. Hence, the fructose and asparagine were reported to enhance the mycelial growth, conidial size, sporulation and sclerotia production of *B. cinerea.* The isolates of *B. cinerea* showed variation in mycelial growth on

Table 2. Effect of temperature on mycelial growth and spore size of different *Botrytis cinerea* isolates

Isolates	Mycelial growth (mm)						Conidia size (µm)*				
	Temperature (°C)						Temperature (°C)				
	10	15	20	25	30	Mean	10	15	20	25	30
BC-1	71.0	88.0	90.0	84.0	77.0	82.0	-	6.54 x 2.66	8.12 x 3.44	9.10 x 4.48	-
BC-6	70.0	88.0	89.0	83.0	76.0	81.0	-	5.44 x 2.22	6.77 x 3.33	7.80 x 4.46	-
BC-8	69.0	88.0	89.0	83.0	75.0	81.0	-	5.66 x 2.33	6.34 x 4.12	7.39 x 5.04	-
KBC-10	63.0	87.0	90.0	80.0	71.0	78.0	6.99 x 3.88	7.11 x 4.09	7.22 X 4.55	7.46 x 4.84	-
KBC-1	57.0	84.0	87.0	75.0	68.0	75.0	NS	NS	NS	NS	-
KBC-14	62.0	86.0	90.0	81.0	71.0	78.0	-	7.23 x 4.33	8.11 x 5.00	8.28 x 5.09	-
KBC-13	60.0	86.0	90.0	80.0	70.0	77.0	-	6.33 x 2.11	7.66 x 3.66	8.82 x 4.66	-
KBC-16	61.0	87.0	90.0	82.0	72.0	78.0	-	6.99 x 4.22	8.79 x 5.66	9.00 x 6.30	-
KBC-5	51.0	81.0	86.0	70.0	60.0	70.0	NS	NS	NS	NS	-
KBC-15	71.0	87.0	90.0	78.0	68.0	79.0	-	6.33 x 2.22	7.88 x 3.88	8.09 x 4.96	-
KBC-9	68.0	89.0	90.0	84.0	78.0	82.0	6.55 x 2.70	5.99 x 2.88	7.44 x 3.23	8.16 x 4.29	-
BC-5	59.0	86.0	90.0	78.0	65.0	76.0	-	5.22 x 2.01	6.33 x 3.55	7.30 x 4.50	-
KBC-2	18.0	56.0	84.0	48.0	20.0	46.0	NS	NS	NS	NS	-
KBC-3	14.0	45.0	82.0	23.0	13.0	37.0	NS	NS	NS	NS	-
KBC-11	59.0	86.0	90.0	77.0	63.0	75.0	-	5.11 x 2.09	6.22 x 3.34	7.44 x 4.15	-
Mean	57.0	82.0	90.0	74.0	63.0	-	-	-	-	-	-
CD (p=0.05)	Isolates = 0.07 Temperature = 0.04 Isolates x Temperature = 0.61										

***** NS= Non sporulating, Absent= -

Table 3. Effect of temperature on colony color and texture size of different *Botrytis cinerea* isolates

Isolates	Morphology characteristics and Texture									
	10		15		20		25		30	
	Color	Texture	Color	Texture	Color	Texture	Color	Texture	Color	Texture
BC-1	Off white	Velvety with radial growth	Off white	Velvety with radial growth	Off white	Velvety with radial growth	Off white	Velvety with radial growth	Off white	Velvety with radial growth
BC-6	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety
BC-8	White	velvety	White	Velvety	White	Velvety	White	Velvety	White	Velvety
KBC-10	Light grey	Fluffy	Light grey	Fluffy	Light grey	Fluffy	Light grey	Fluffy	Of white	Fluffy
KBC-1	Off white	Cottony	Off white	Cottony	Off white	Cottony	Off white	Cottony	Off white	Cottony
KBC-14	Ashy off white	Cottony	Ashy off white	Cottony	Ashy off white	Cottony	Ashy off white	Cottony	Off white	Cottony
KBC-13	Off white	Cottony	Off white	Cottony	Ashy off white	Cottony	Ashy off white	Cottony	Off white	Cottony
KBC-16	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety
KBC-5	Off white	Cottony	Off white	Cottony	Off white	Cottony	Off white	Cottony	Off white	Cottony
KBC-15	Dark grey	Fluffy	Fluffy	Fluffy	Dark grey	Fluffy	Dark grey	Fluffy	Dark grey	Fluffy
KBC-9	Dark grey	Cottony	Dark grey	Cottony	Dark grey	Fluffy	Off white	Fluffy	Off white	Fluffy
BC-5	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety
KBC-2	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety
KBC-3	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety	Off white	Velvety
KBC-11	Off white	Fluffy	Off white	Fluffy	Off white	Fluffy	Off white	Fluffy	Off white	Fluffy

Table 4. Sporulation and production of sclerotia of isolates of *Botrytis cinerea* at different temperatures

Isolates	Degree of Sporulation*					Production of Sclerotia**				
	Temperature (℃)									
	10	15	20	25	30	10	15	20	25	30
BC-1	+	+++++	++++	+++	-	++	++	+	-	-
BC-6	++	+++++	++++	+++	-	++	++	+	-	-
BC-8	++	+++++	++++	+++	-	++	++	+	+	-
KBC-10	++	+++++	++++	+++	+	++	++	+	-	-
KBC-1	NS	NS	NS	NS	NS	NP	NP	NP	NP	NP
KBC-14	++	+++++	++++	+++	+	++	++	+	-	-
KBC-13	++	+++++	++++	+++	-	++	++	+	-	-
KBC-16	++	+++++	++++	+++	+	++	++	+	+	-
KBC-5	NS	NS	NS	NS	NS	NP	NP	NP	NP	NP
KBC-15	++	+++++	+++	+++	+	++	++	+	+	-
KBC-9	++	++++	+++	+++	+	++	++	+	+	-
BC-5	++	++++	+++	++	+	++	++	+	-	-
KBC-2	NS	NS	NS	NS	NS	NP	NP	NP	NP	NP
KBC-3	NS	NS	NS	NS	NS	NP	NP	NP	NP	NP
KBC-11	+	+++	++	++	+	++	++	+	-	-

*+ + + += Excellent, + + += Very Good, + + = Good, + = Poor and NS= Non sporulating
**Sclerotia Non- producing = NP, Good= +, Excellent= ++, Absent = -

Table 5. Effect of different carbon sources *in vitro* on the growth and sporulation of *Botrytis* isolates

Isolates	Dry weight (mg)						Conidial size (µm)*					Sporulation*				
	Control	Galactose	Dextrose	Fructose	Raffinose	Mean	Control	Galactose	Dextrose	Fructose	Raffinose	Control	Galactose	Dextrose	Fructose	Raffinose
BC-1	80	250	430	460	330	310	8.22 x 4.33	10.56 x 4.87	11.22 x 4.99	9.88 x 4.77	9.22 x 4.66	+	+ + + +	+ + +	+ + + +	+ + + +
BC-6	110	450	420	390	540	380	-	5.22 x 2.09	4.99 x 2.01	5.77 x 2.11	4.66 x 2.02	-	+	+	+	+
BC-8	100	220	390	410	400	310	6.90 x 4.02	7.89 x 5.04	8.01 x 4.90	8.66 x 5.44	8.22 x 5.01	+	+ + +	+ + +	+ + +	+ + +
KBC-10	150	450	380	660	560	440	7.66 x 3.55	10.11 x 3.99	9.98 x 3.66	10.45 x 4.80	10.33 x 4.11	+ +	+ + + +	+ +	+ + + +	+ + + +
KBC-1	080	320	280	360	270	260	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-14	100	410	440	100	380	290	-	9.66 x 5.11	9.87 x 5.10	-	9.22 x 5.01	-	+	+ + +	-	+
KCB-13	120	390	290	300	240	270	7.45 x 2.99	8.99 x 4.78	8.22 x 4.22	8.77 x 4.55	8.01 x 3.99	+	+ +	+	+	+
KBC-16	200	490	460	540	510	440	9.11 x 5.99	11.89 x 6.33	11.22 x 5.99	11.66 x 6.01	11.33 x 5.99	+ +	+ + + +	+ + +	+ + +	+ + + +
KBC-5	120	470	380	510	400	380	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-15	110	420	400	460	330	350	6.22 x 3.55	7.11 x 3.99	7.22 x 4.00	7.88 x 4.11	6.99 x 3.22	-	+	+	+	+
KBC-9	170	500	480	640	580	470	10.01 x 4.22	11.01 x 5.01	10.88 x 4.22	11.22 x 5.22	11.09 x 5.04	+ +	+ + + +	+ + + +	+ + + +	+ + + +
BC-5	150	380	340	410	300	320	7.77 x 4.11	8.22 x 4.23	8.01 x 4.09	8.44 x 4.99	8.02 x 3.99	+	+ + +	+	+ + +	+ +
KBC-2	90	300	280	320	250	250	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-3	0	0	0	0	100	20	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-11	100	400	120	440	360	280	-	5.88 x 2.99	-	6.55 x 3.10	5.33 x2.01	-	+	-	+	+
Mean	110	360	340	370	400	-	-	-	-	-	-		-	-	-	-
CD (p=0.05)	Isolates = 0.007															
	Carbon sources = 0.004															
	Isolates x Carbon sources = 0.01															

** + + + += Excellent, + + += Very Good, + + = Good, + = Poor, NS= Non sporulating and Absent = -

Table 6. Effect of different nitrogen sources *in vitro* on growth and sporulation of *Botrytis* isolates

Isolates	Dry weight						Spore size(µm)*					Sporulation*				
	Control	Ammonium nitrate	Glutamine	Potassium nitrate	Asparagine	Mean	Control	Ammonium nitrate	Glutamine	Potassium nitrate	Asparagine	Control	Ammonium nitrate	Glutamine	Potassium nitrate	Asparagine
BC-1	140	400	420	490	570	400	8.99 x 3.22	11.22 x 4.77	11.66 x 4.90	11.99 x 5.02	12.10 x 5.99	+ +	+ + + +	+ + + +	+ + + +	+ + + +
BC-6	0	380	320	450	520	330	-	5.99 x 4.01	5.33 x 3.99	6.22 x 4.22	6.55 x 4.22	-	+	+	+	+ +
BC-8	120	480	500	540	610	450	6.55 x 3.99	7.99 x 4.98	8.22 x 5.01	8.55 x 5.11	8.77 x 5.44	+	+ + +	+ + +	+ + +	+ + +
KBC-10	90	460	510	370	540	390	7.88 x 3.66	10.12 x 3.99	10.22 x 4.33	9.99 x 3.55	10.45 x 4.99	+ +	+ + + +	+ + + +	+ + + +	+ + + +
KBC-1	70	000	0	320	140	110	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-14	100	400	370	430	480	360	5.88 x 3.55	7.88 x 4.98	8.66 x 5.01	8.77 x 5.77	8.99 x 5.99	+	+ +	+ +	+ +	+ +
KCB-13	100	370	350	480	500	360	5.99 x 2.55	7.11 x 3.01	7.01 x 3.02	7.44 x 3.22	7.99 X 3.99	+	+ +	+ +	+ +	+ +
KBC-16	120	420	290	370	300	300	6.88 x 3.88	10.88 x 5.99	9.66 x 4.22	10.11 x 4.99	9.99 x 4.88	+	+ +	+ +	+ +	+ +
KBC-5	0	450	270	380	490	320	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-15	100	420	320	390	480	340	-	7.11 X 3.99	6.99 X 3.22	7.22 X 4.11	7.88 X 4.22	-	+ +	+ +	+ +	+ +
KBC-9	110	460	41	500	520	400	9.88 x 4.33	11.11 x 5.01	10.99 x 4.89	11.33 x 5.22	12.11 x 5.66	+ +	+ + + +	+ + + +	+ + + +	+ + + +
BC-5	000	420	370	480	500	350	-	8.11 x 3.92	7.99 x 3.77	8.44 x 4.11	8.99 x 4.33	-	+ +	+ +	+ +	+ +
KBC-2	090	460	340	220	380	300	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-3	110	410	380	27	450	320	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
KBC-11	120	280	490	380	340	320	-	6.55 x 3.01	7.88 x4.11	7.22 x 4.01	6.77 x 3.99	+	+ +	+ +	+ +	+ +
Mean	80	390	360	410	450											
CD (p=0.05)			Isolates=0.006													
			Nitrogen sources=0.003													
			Isolates x Nitrogen sources=0.013													

** + + + += Excellent, + + += Very Good, + + = Good, + = Poor, NS= Non sporulating and Absent = -

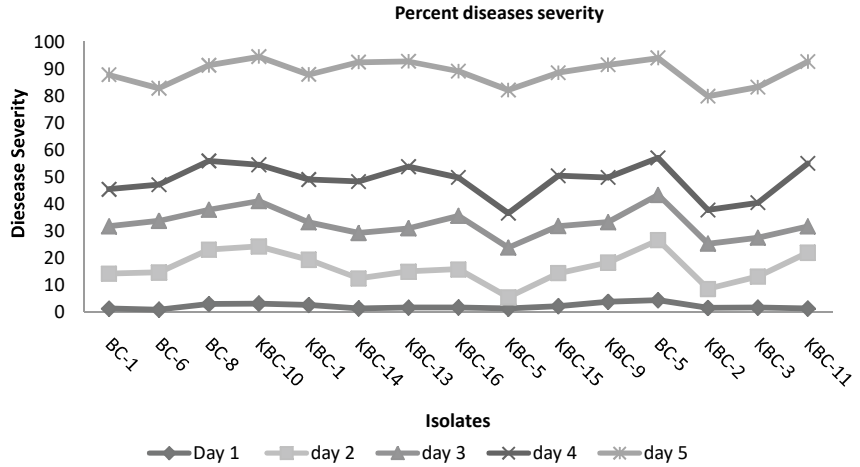

Fig. 1. Per cent disease severity of different commercial varieties of gladiolus against *Botrytis* isolates recorded for five days (*in vitro*)

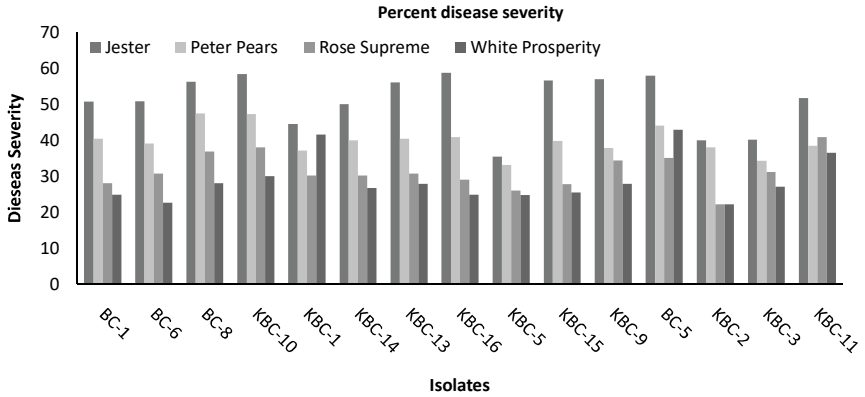

Fig. 1. Per cent disease severity of different commercial varieties of gladiolus against *Botrytis* isolates recorded for five days (*in vitro*)

liquid nutrient media supplemented with different carbon and nitrogen sources. Among different carbon sources the *B. cinerea* isolates showed maximum mycelial growth and sporulation in fructose at micromolar concentration than glucose (Doehlemann et al 2005, Waghmare et al 2011) concluded that the fructose and asparagine were the best carbon and nitrogen sources for the growth of pathogen. This result is supported with the findings of earliest researcher (Kaur et al 2016, Sultana et al 2017).

Pathological variability: The maximum disease severity (Fig. 1-2) developed on florets of gladiolus was shown by BC-5 (57.00%) and minimum severity was recorded by KBC-5 (36.58%). Most of the isolates didn't produced disease on cultivars Rose Supreme and White Prosperity even after 48 hours of inoculation followed by KBC-1, KBC-3, KBC-9, KBC-10 and KBC-11 showed disease severity on Rose Supreme and KBC-1 and BC-5 on White Prosperity. Maximum disease severity was shown by KBC-16 (58.78%) on Jester cultivar of gladiolus whereas, minimum severity was given by KBC-5 (34.47%). However in fifth day, the flowers were completely covered with the fungal growth and get rotted completely. All the isolates reported to be virulent on all the four cultivars studied. These results are in consonance with Riaz (2010) and Petrasch et al 2019. According to the latest taxonomical analysis, over 35 *Botrytis* species was found, out of which *Botrytis cinerea* is the most popular and accomplished (Richard 2021).

CONCLUSION

The *Botrytis* spp. belongs to the family *Sclerotiniaceae*, which contain fungal species all over the world, it causing huge damage to agricultural farms. The *B. cinerea* species is the renowned member of this genus, which shows a facultative secretive endophytic behaviour ('hide and seek'). Usually, when a pathogen, whether virulent or non- virulent, contains this level of plasticity in their genome that favors it to traverse

distinct niches and it changes to different epidemiological conditions, because of this its presence detected easily in various geographical and climatic regions of the India. However, numerous details about the variability of *B. cinerea* is still unknown. Here, we recapitulate, different carbon and nitrogen sources, high humidity and optimum temperature that favors the growth and infection strategies under *in vitro* conditions. Furthermore, the research on the variability of isolates will continue to be resourceful that should be scrutinize with substantial efforts to have improve and acceptable agricultural practices for the well- being of our planet.

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Spatial Distribution and Identification of Begomovirus(es) Infecting Muskmelon in Punjab, India

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***Abstract*:** Muskmelon (*Cucumis melo* L.) has considerable share in overall cucurbit vegetable cultivation in Punjab state. The successful production of the crop is threatened by number of biotic stresses. Among these, whitefly transmitted begomoviruses are very important. In order to know the prevalence of these viruses under Punjab conditions, major muskmelon growing areas in different districts *viz*., Jalandhar, Kapurthala, Ludhiana, Fatehgarh Sahib, Sangrur and S.A.S. Nagar were surveyed. Further, confirmation of the prevalent virus(es) was done by PCR assays using virus specific markers. The perusal of the data revealed that district wise maximum incidence of begomovirus was observed in Sangrur (48.93%) and minimum in Ludhiana district (24.25%). In Kapurthala, S.A.S. Nagar, Jalandhar and Fatehgarh Sahib districts, 32.37, 30.89, 26.41 and 26.00% incidence of the virus was recorded, respectively. The PCR analysis with begomovirus specific primers, PALIc1960 and PARIv722 confirmed the presence of begomovirus(es) in 65% of the collected samples. Further, PCR assay of the selected samples using primers specific to tomato leaf curl New Delhi virus, tomato leaf curl Palampur virus and squash leaf curl virus confirmed the association of these viruses in different muskmelon growing regions of Punjab.

***Keywords*:** Muskmelon, Begomovirus, Tomato leaf curl New Delhi virus, Tomato leaf curl Palampur virus, Squash leaf curl virus

Muskmelon crop is highly ranked in cucurbit cultivation around the world. Worldwide production of muskmelon is 28.61 million tonnes. In India, 75 thousand ha area is under muskmelon cultivation with a production of 1.478 million tonnes per annum making India the third largest muskmelon producing country in the world (FAOSTAT 2021). In Punjab about 139.79 thousand tonnes muskmelon is being produced from an area of 7.01 thousand ha used for growing the crop (Anonymous 2021). In the state, the muskmelon crop is sown after mid-February and harvesting is carried out till June. The average temperature varies from; min. 19.92-26.76°C; to maximum 22.73-43.28°C during this period. As the temperature starts rising in March onwards, the population of begomovirus vector *i.e.,* whitefly also begins to increase. Which then blowout the begomovirus in muskmelon fields and symptoms of begomovirus start to appear. Muskmelon crop is prone to various viral diseases and is reported to be attacked by different group of viruses (Kang and Sandhu 2007). Among these, circular, single standard DNA viruses of genus begomovirus, family Geminiviridae, are the most important vegetable viruses infecting various cucurbits including muskmelons (Moriones and Navas-Castillo 2000). Distribution and importance of begomoviruses have been increased in tropical and subtropical areas of the world in recent decades causing considerable yield loss in many economically important crops (Varma and Malathi 2003). Begomoviruses are transmitted by whiteflies *Bemisia tabaci* (Hemiptera: Aleyrodidae) in persistent, non-circulative manner and infect dicotyledonous crops. Begomoviruses symptomatology include, mosaic, yellowing of new leaves, leaf curling, stunting, increased vein thickness, rough fruit skin and longitudinal fissures on fruits (Mnari-Hattab et al 2015). The virus-infected plants remain stunted and weak as compared to the healthy plants and considerable yield losses are endured. Tomato leaf curl New Delhi virus and tomato leaf curl Palampur virus were found to be prevalent in different melon growing regions of the world (Malik et al 2011, Mnari-Hattab et al 2015). Furthermore, melon chlorotic leaf curl virus, cucurbit leaf crumple virus, squash leaf curl virus and watermelon chlorotic stunt virus, are also established to infect melons (Sobh et al 2012). Begomovirus(es) have wide host range and pose stringent obstacle to successful cultivation of vegetable crops. In order to extrapolate the occurrence, degree of manifestation and identification of begomovirus(es) in muskmelon crop in Punjab state, the present study was carried out.

MATERIAL AND METHODS

Survey for distribution and prevalence of begomovirus: In order to assess the incidence and prevalence of begomovirus in muskmelon, surveys were conducted in

different muskmelon growing districts of Punjab *viz.,* Ludhiana, Sangrur, Kapurthala, Jalandhar, S.A.S. Nagar and Fatehgarh Sahib in the year 2019-20. Diagnosis of the disease was based on typical symptoms i.e., stunting, curling, yellowing of plants in the field. Symptomatic leaf samples were collected and brought to laboratory for analysis and detection of the virus(es). For virus incidence, observations were recorded on young leaves of randomly selected 5-10 plants from four corners C1, C2, C3, C4 and one central patch C5 from each field and per cent incidence was calculated. Virus disease severity grade was measured on a (0-5) scale given by Kumar et al (2006). Where, symptom severity grade 0 = no visual symptoms; 1= 0-5% curling of upper leaves; 2= 6-25% curling of leaves and swelling of veins; 3= 26-50% curling puckering and yellowing of leaves and swelling of veins; 4= 51-75% leaf curling and stunted plant growth and blistering of internodes; 5= More than 75% curling deformed small leaves, stunted plant growth with small flowers and no or small fruit set. Disease incidence (DI) and per cent disease index (PDI) i.e., disease severity was then calculated using the following formulas:

$$\text{Per cent diseases incidence (DI)} = \frac{\text{Number of infected plants}}{\text{Total number of plants observed}} \times 100$$

$$\text{Per cent diseases index (PDI)} = \frac{\text{Sum of all the numerical ratings}}{\text{Total number of plants} \times \text{Maximum disease grade}} \times 100$$

Detection and identification of virus(es) infecting muskmelon: Symptomatic leaf samples were collected in ice box from different districts during the survey and were categorised according to the symptom variability. One set of leaf samples was stored in -80°C for further studies. The all the samples were categorised based on their symptoms. To identify the viruses associated with these samples DNA based detection methods were used. Total nucleic acid from the young symptomatic leaves of muskmelon collected during survey was isolated using the cetyl trimethyl ammonium bromide (CTAB) method (Lodhi et al 1994). Presence of ssDNA viruses was confirmed using begomovirus specific PALIc1960 and PARIv722 primers (Rojas et al 1993). The PCR amplification was done in a thermal cycler with initial-denaturation at 94ºC for 1 minute, followed by 35 cycles each consisting of denaturation at 94ºC for 50 sec, annealing at 52ºC for 45 sec followed by extension at 72ºC for 1.30 min and final extension for 15 minutes at 72ºC. After the completion of the reaction, the products were kept at -20ºC prior to gel analysis. Amplified PCR products were electrophoresed in 1.0 per cent agarose gel. For further confirmation, the isolated DNA of selected begomovirus positive samples was again subjected to PCR amplification using tomato leaf curl New Delhi virus (ToLCNDV), tomato leaf curl Palampur virus (ToLCPalV) and squash leaf curl virus (SqLCV) specific primers (Table 1).

RESULTS AND DISCUSSION

Prevalence and incidence of begomovirus(es) infecting muskmelon: In Punjab, nursery of muskmelon is sown around mid-January to mid-February and transplanted in the field around 2nd fortnight of February till mid-March. The crop remains in the field from March till the June. The surveys were conducted during the mid-season of the crop to record incidence and prevalence of begomovirus(es). Perusal of data revealed that the highest incidence of begomovirus(es) (48.93%) was observed in Sangrur district, while Ludhiana district recorded the lowest begomovirus incidence (24.25%). Similarly, Sangrur district had the maximum (28.16%) and Ludhiana district had minimum (14.35%) per cent disease index (PDI) (Table 2). Further, it was observed that frequency of occurrence of begomovirus was 100 per cent in all the muskmelon growing districts of Punjab under study. In majority of muskmelon growing areas being surveyed in the current study farmers used to follow potato-muskmelon-rice as crop rotation.

Identification of begomovirus(es) associated with muskmelon: Different types of symptoms were observed

Table 1. Primers used for detection of tomato leaf curl New Delhi virus, tomato leaf curl Palampur virus and squash leaf curl virus

Primer	Expected product size	Primer sequence data	Reference
Begomovirus specific primer: PALIc1960 PARIv722	~1280bp	5' ACNGGNAARACNATGTGGGC 3' 3' GGNAARATHTGGATGGA 5'	Rojas et al (1993)
ToLCNDV primer: CRNDv30 CRNDc1181	~1180bp	5'GCCCTCAACCAATGAAATTCAC3' 5'GAGAGTCTTCAAAACCCAGGTCC3'	Reddy et al (2005)
ToLCPalV primer: Palampur F Palampur R	~875bp	(Personal communication, Yogesh Kumar, IHBT, Palampur, Himachal Pradesh, India)	
SqLCV primer: SqLCV F SqLCV R	~1000bp	(Personal communication, Dr. Abhishek Sharma, PAU, Ludhiana, Punjab, India)	

during the survey for incidence of begomovirus(es) in muskmelon. These were; leaves showing yellowing only, downward curling of leaves no yellowing, leaves showing yellowing + puckering + curling, yellowing + puckering of leaves, leaves showing yellowing and downward curling, curling + puckering of leaves, yellowing of leaves with reduction in size and stunting of vines (Table 3, Fig. 1). All the leaf samples collected during the survey were segregated based on type of symptoms exhibited and representative samples for each district were selected for detection of begomovirus(es) associated with muskmelon crop in Punjab. In all, 23 symptomatic leaf samples (showing varying symptoms) representing different districts under survey were selected. The selected samples were first subjected to PCR

Table 2. Prevalence, incidence, and severity of Begomovirus in major muskmelon growing areas of Punjab

Village	Global position	Area (ha)	Begomovirus incidence (%)	Begomovirus PDI* (%)
Kapurthala district				
Sheikhupur	31.3544°N 75.3609°E	8.70	35.60 (28.00-44.00) **	19.36 (14.80-23.60)
Biharipur	31.4040°N 75.1419°E	10.72	28.86 (20.00-36.00)	15.26 (10.40-20.00)
Brindpur	31.3468°N 75.3565°E	4.86	32.67 (24.00-44.00)	18.33 (11.60-24.80)
		Mean	32.37	17.65
Jalandhar district				
Malsian	31.1292°N 75.3492°E	18.62	24.73 (16.00-48.00)	12.36 (6.40-30.80)
Chachowal	31.2249°N 75.6528°E	6.47	39.50 (36.00-44.00)	23.80 (21.20-26.40)
Rupewali	31.1455°N 75.3033°E	5.87	15.00 (10.00-22.00)	7.80 (5.20-12.00)
		Mean	26.41	14.65
Ludhiana district				
Vegetable Farm, PAU	30.9041°N 75.8066°E	0.40	35.00 (32.00-40.00)	21.40 (16.80-24.80)
Khwajake	30.9611°N 75.9224°E	8.09	13.50 (10.00-16.00)	7.30 (5.60-9.60)
		Mean	24.25	14.35
Fatehgarh Sahib district				
Haripur	31.0629°N 75.5168°E	8.30	26.00 (22.00-32.00)	14.40 (11.60-18.00)
		Mean	26.00	14.40
Sangrur district				
Bhaini Kalan	30.4681°N 75.9064°E	2.43	50.00 (46.00-54.00)	29.60 (26.80-31.60)
Burj	30.4780°N 75.8425°E	3.24	44.00 (36.00-52.00)	26.80 (22.80-30.80)
Takhar Kalan	30.5118°N 75.8229°E	9.31	52.80 (52.00-54.00)	28.08 (25.60-30.80)
		Mean	48.93	28.16
S.A.S. Nagar district				
Tangori	30.5949°N 76.7059°E	5.67	33.33 (32.00-36.00)	18.67 (16.80-21.60)
Kurara	30.5993°N 76.7272°E	2.43	28.00 (23.00-32.00)	13.60 (10.80-16.60)
Mote Majra	30.5856°N 76.6976°E	4.05	31.33 (32.00-34.00)	13.80 (12.00-15.60)
		Mean	30.89	15.36

* Per cent disease index; ** Values in parenthesis are range of the parameters

analysis with begomovirus specific PALIc1960 and PARIv722 primers (Rojas et al 1993) to confirm the presence of begomovirus(es). The results showed that about 65 per cent samples were positive for presence of begomovirus(es) showing desired amplicon of ~1200bp with PALIc1960 and PARIv722 primers (Table 3, Fig. 2). This confirmed the association of begomoviruses with muskmelon crop in Punjab. The same set of samples when subjected to PCR analysis again using tomato leaf curl New Delhi virus (ToLCNDV), tomato leaf curl Palampur virus (ToLCPalV) and squash leaf curl virus (SqLCV) specific primers, all the three begomoviruses (ToLCNDV, ToLCPalV and SqLCV) were found to be infecting muskmelon crop under Punjab conditions. The PCR analysis also revealed mixed infection of more than one virus in some samples (Table 3). Tomato leaf curl New Delhi virus (ToLCNDV) was found to be more prevalent in Jalandhar, Kapurthala, Sangrur and Fatehgarh Sahib district. One sample from Ludhiana district also showed presence of ToLCNDV. However, no amplification of ToLCNDV was observed from all the four samples subjected to PCR analysis from S.A.S. Nagar (Table 3, Fig. 3). ToLCPalV was found more prevalent in S.A.S. Nagar as four samples out of total five samples were found positive (Fig. 4). Prevalence of ToLCPalV was also there in muskmelon

Table 3. Symptom variability and summary of marker-based detection of Begomovirus(es) infecting muskmelon in different districts of Punjab

Leaf symptoms	Begomovirus	ToLCNDV	ToLCPalV	SqLCV
Jalandhar district				
Curling	-	+	-	-
Yellowing, puckering, curling	-	+	-	+
Yellowing, stunting, mosaic like symptoms	+	+	+	+
Kapurthala district				
Yellowing	+	-	+	-
Yellowing, puckering	+	+	-	-
Yellowing, curling	+	+	+	-
Sangrur district				
Curling, puckering	+	+	-	-
Yellowing, mosaic like symptoms	+	-	+	+
Yellowing, stunting, small leaves	+	+	+	+
Fatehgarh Sahib district				
Yellowing, puckering	-	+	-	+
Curling	+	+	-	-
Yellowing, curling	+	+	-	+
Curling	+	+	-	-
S.A.S Nagar district				
Yellowing	+	-	+	+
Yellowing	+	-	+	+
Yellowing	-	-	-	-
Yellowing	-	-	+	-
Yellowing	+	-	+	-
Ludhiana district				
Yellowing	+	-	+	+
Yellowing	-	-	-	-
Yellowing	-	-	-	-
Yellowing, small leaves	-	-	-	+
Curling	+	+	-	-

ToLCNDV=Tomato leaf curl New Delhi Virus; ToLCPalV=Tomato leaf curl Palampur virus; SqLCV= Squash leaf curl virus; (+) = presence of virus; (-) = absence of virus

growing areas of Jalandhar, Kapurthala, Sangrur and Ludhiana. However, none of the sample from Fatehgarh Sahib found positive for ToLCPalV. Squash leaf curl virus was also found associated with muskmelon crop in all the districts under study; expect Fatehgarh Sahib, where none of the four samples showed presence of SqLCV (Table 3; Fig. 5).

Symptoms with yellowing, curling, leathery leaves, reduced leaf size and stunted growth clearly indicated the

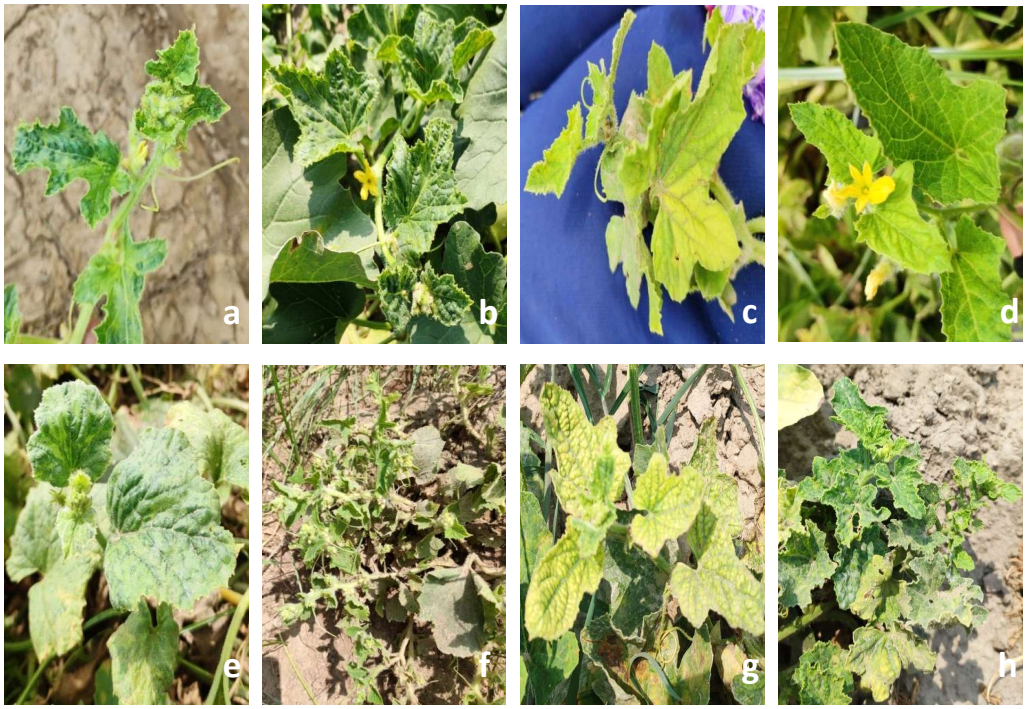

Fig. 1. Begomovirus symptom variability observed during the survey. (a & b): upward curling and puckering of leaves; (c & d): yellowing of leaves; (e): downward curling & puckering of leaves with reduction in size; (f): upward curling and stunting of vine; (g & h): yellowing, puckering and vein clearing

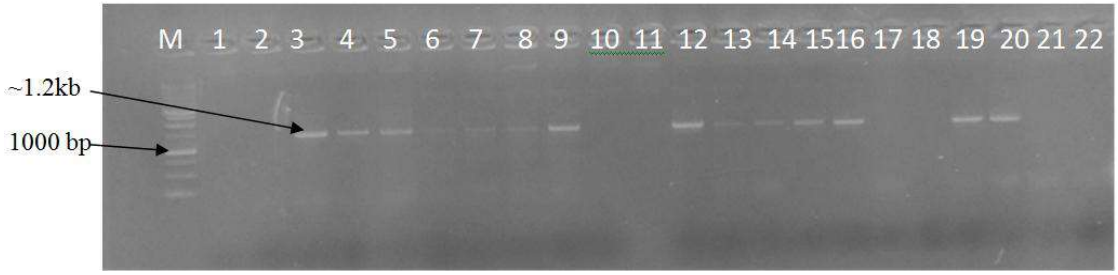

Fig. 2. Agarose gel (1%) showing amplicon of ~1.2kb with PALIc1960 and PARIv722 primer specific to begomovirus in different samples collected during the survey. (M-marker - 1000bp; 1-22 samples)

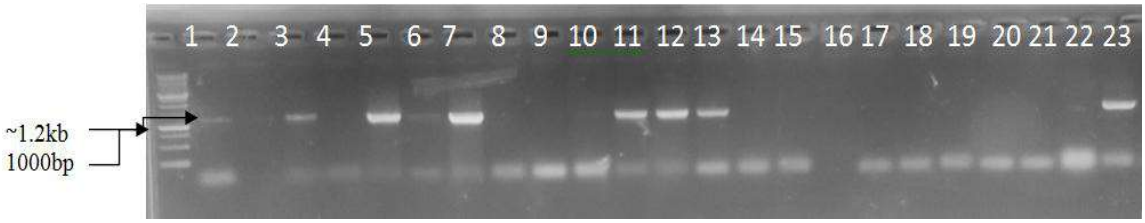

Fig. 3. Agarose gel (1%) showing amplicon of ~1.2kb with CRNDv30 and CRNDc1181primer specific toTomato leaf curl New Delhi virus. (M-marker -1000bp; 1-23 samples)

Fig. 4. Agarose gel (1%) showing amplicon of ~875bp with primer specific to Tomato leaf curl Palampur virus. (M-marker -1000bp; 1-23 samples)

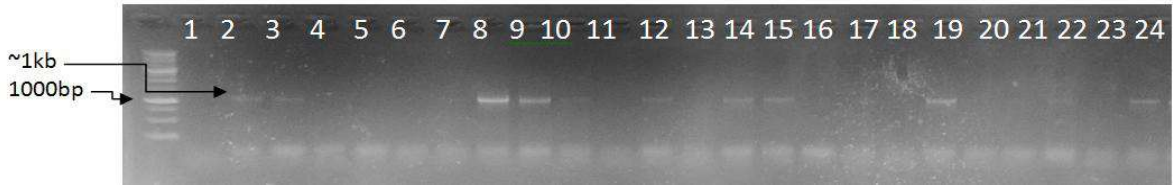

Fig. 5. Agarose gel (1%) showing amplicon of 1kb with primer specific to Squash leaf curl virus. (M-marker -1000bp; 1-24 samples)

infection of begomovirus (Sinha et al 2011). The ToLCPalV has been found associated with muskmelon crop and producing a serious yellow leaf curl disease in Pakistan (Malik et al 2011). Yadani-Khameneh et al (2013) reported tomato ToLCNDV infecting muskmelon in Iran for the first time. The infection of ToLCNDV on cucurbit crops like melon, cucumber and zucchini was also described by Mnari-Hattab et al (2015). In Punjab, Sharma et al (2015) first time documented the mixed infection of zucchini yellow mosaic virus (ZYMV) and a (ToLCNDV) in bitter gourd crop. Thereafter, Dhkal et al (2020a, b) confirmed the association of ToLCPalV and ToLCNDV with muskmelon crop causing leaf yellowing and curling in India. Later on, Venkataravanappa et al (2021) also reported ToLCPalV infecting muskmelon and cucumber in Uttar Pradesh.

CONCLUSIONS

The present study reveals that whitefly transmitted begomoviruses were prevalent in all muskmelon growing areas of Punjab and caused disease incidence ranging from 13.50 to 52.80 per cent in year 2019-20. Distinctive symptoms due to the infection were yellowing, curling, yellowing plus curling, puckering of leaves, mosaic like symptoms, and stunted growth of muskmelon plants. Tomato leaf curl New Delhi virus, tomato leaf curl Palampur virus, and squash leaf curl virus were identified to be associated with muskmelon crop singly or in mixed infection. The information generated during the present study can be helpful in planning management strategies and identifying resistant sources to combat the begomoviruses infecting muskmelon in Punjab. Mixed infection may lead to mutations, recombination, and re-assortment in viral genome which will further result in evolutionary development of new virus strains which may be more contagious and cause severe damage to the crop. In future, whole genome characterization could be done to elucidate begomovirus evolution in Punjab.

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Transmission of Begomovirus and Groundnut Bud Necrosis Virus Infecting Melons in Punjab

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Abstract: Viral diseases were reported to be a major constraint in the cultivation of melons under Punjab conditions. During this study yellows and leaf curl symptoms were recorded on muskmelon crop which was due to the infection of begomovirus whereas, in watermelon crop infection of groundnut bud necrosis virus (GBNV) was recorded that leads to the production of necrosis symptoms. Transmission of begomovirus and GBNV was tested through mechanical transmission, aphid transmission, whitefly transmission and seed transmission. In muskmelon crop where begomovirus was associated with yellows and leaf curl symptoms, 100% transmission was recorded through whiteflies whereas this virus has not shown transmission through other remaining methods. In whitefly based transmission, symptoms were observed 11 days after inoculation (DAI). In watermelon only 1% transmission of GBNV was observed through seeds whereas this virus was not transmitted through other tested methods. Symptoms were observed in the infected plants 34 days after sowing (DAS). Information regarding the mode of transmission of viral diseases could be very useful for their effective management.

Keywords: Watermelon, Muskmelon, Transmission, Begomovirus, Groundnut bud necrosis virus

Melon (*Cucumis melo* L.) is an important vegetable crop that can be used in several ways viz. as fresh vegetable, dessert fruit, cooked, dried or processed for juice and flavoring. Seeds of melons can be roasted and consumed like nuts. Melon seeds are the source of high quality cooking oil and high-protein seed meal (McCreight et al 2011). The world production of melons in 2019 was estimated to be 27.50 million tonnes from 1.03 million ha of land, however, in India production of melons was estimated to be 1.27 million tones which was 4.6% of world's production from 0.06 million ha area (Anonymous 2019). Throughout the world melons are attacked by more than 30 viruses that include both DNA and RNA containing viruses (Zitter et al 1996).

Mosaic, yellows, fruit malformation, puckering of leaves, mosaic and blistering on fruits, yellowing of veins and veinlets, leaf narrowing, mosaic mottling, malformation of stem and leaves, appearance of chlorotic spots on leaves, vein banding, leaf filiformity, leaf resetting, necrosis and enations were some important symptoms produced as a result of viral infection on cucurbits (Holkar et al 2016, Nagendran et al 2017 and Dhkal et al 2020). Worldwide these symptoms were reported to be produced by the infection of viruses belonging to the genera *Begomovirus*, *Potyvirus*, *Cucumovirus*, *Tospovirus*, *Tobamovirus*, *Tymovirus*, *Nepovirus* and *Polerovirus* (Liu et al 2009, Zitter and Murphy 2009, Abdalla et al 2012, Sobh et al 2012, Dreher et al 2012, Mansilla et al 2013, Johnson et al 2013, Holkar et al 2016 and Dhkal et al 2020).Viruses infecting cucurbits are known to be transmitted by different insect vectors, however some of these viruses are also known to be transmitted by seed (Tobias et al 2008, Simmons et al 2011 and Reingold et al 2015). During 2017-18, yellows and leaf curl symptoms on muskmelon crop whereas necrosis symptoms in watermelon were observed on the stem and leaf of infected plants. Earlier in Punjab these symptoms were not commonly observed on the muskmelon and watermelon crop so no information about its transmission is available. Current study was designed to identify the transmission of necrosis (in watermelon) and yellows and leaf curl (in muskmelon) symptoms under Punjab condition.

MATERIAL AND METHODS

Detection of viruses associated with the symptoms: For the detection of virus associated with leaf curl and yellows symptom of muskmelon *Begomovirus* specific primers developed by Rojas et al (1993) viz. PALIc (5'ACNGGNAARACNATGTGGGC3') and PARIv (5'GGNAARATHTGGATGGA3') were used as begomovirus was earlier reported to be associated with muskmelon crop in Punjab (Dhkal et al 2020). The PCR amplification was carried out in a thermal cycler with initial cycle of denaturation at 94ºC for 1 minute, annealing at 52ºC for 1.5 minutes and elongation of 72ºC for 2 minutes, followed by 35 cycles each consisting of denaturation at 94ºC for 50 sec, annealing at 52ºC for 45 sec followed by extension at 72ºC for 1.5 min and final extension for 15 minutes at 72ºC. After the completion of

the reaction, the products were kept at -20ºC prior to gel analysis. Amplified DNA fragments were electrophoresed in 1.0 percent agarose gel. However, in watermelon Groundnut bud necrosis virus (GBNV) specific antisera procured from Agdia Inc (Elkhart, USA) were used as Holkar et al (2016) reported the association of this virus with necrosis symptoms of watermelon. The procedure for DAS/TAS-ELISA given by Clark and Adams (1977) was used as per manufacturer's instruction. End point absorbance readings (OD) were taken by ELISA reader (Tecan, Austria) at 405 nm.

Maintenance of plants for transmission study: For sap and insect transmission nursery of muskmelon and watermelon was raised in 15 x 10 cm and 100 gauge thick polyethylene bags filled at the base with equal proportions of well-rotted manure and soil. Two seeds per bag of the Punjab Sunehri variety in muskmelon and Barmeri variety in watermelon were sown to a depth of 1.5 cm in the first half of February. Seedlings were maintained as mentioned in the Package of Practices for Growing Vegetables, PAU, Ludhiana (Anonymous 2017). One month old two true leaf stage seedlings were then used for the transmission studies at a vegetable research farm, Department of Vegetable Sciences, in the second half of April 2018. For seed transmission, seeds were sown in 96 well plug trays.

Transmission

Sap transmission: Young leaf of the identified infected plants was crushed in phosphate buffer (pH 7.0) (0.03 M Na_2HPO_4 containing 0.2 per cent Na-diethyldithio-carbamate (DIECA) (1:4), 400 mesh carborundum (75 mg/ml) + activated charcoal (75 mg/ml) and then this sap was used to inoculate the healthy seedlings of muskmelon (Punjab Sunehri) and watermelon (Barmeri) at two true leaf stage. After inoculation plants were observed for the symptom development regularly.

Insect Transmission

Aphid transmission: Non-viruliferous aphids (*Aphis gossypii*) were raised on healthy Chinese cabbage. These non-viruliferous aphids were then starved in the Petri dish. These starved aphids were fed on the virus infected leaf of muskmelon for 10 min acquisition access time (AAT), then transferred to healthy muskmelon (Punjab Sunehri) and watermelon (Barmeri) test plants of two true leaf stage for 2hrs. Inoculated plants were then kept in insect proof cage and observed for the symptom appearance regularly and observed up to 35 days at weekly intervals. After 35 days of inoculation the youngest leaf of the plant was taken for further serological and molecular analysis.

Whitefly transmission: The non-viruliferous whitefly (*Bemisia tabaci*) was reared on virus free cotton plants. These non-viruliferous whitefly was collected in plastic bottle and left on infected twig of muskmelon for 24hrs acquisition access time (AAT). These viruliferous whitefly were transferred to healthy muskmelon (Punjab Sunehri) and watermelon (Barmeri) test plants of two true leaf stage for 24hrs of Inoculation feeding Period (IFP). The inoculated plants were sprayed after 24 hrs of inoculation using insecticide. These inoculated plants were kept in an insect proof cage and observed up to 35 days at weekly intervals for appearance and type of symptoms. After 35 days of inoculation the youngest leaf of the plant was taken for further serological and molecular analysis.

Seed transmission: Seeds were collected from infected fruits of highly susceptible varieties of muskmelon (Punjab Sunehri and Hara Madhu) and watermelon (Barmeri) showing typical virus symptoms. The seeds (100 seeds/ variety) were sown under insect proof cage in sterilized soil and observed for symptom expression. After germination of seeds, seedlings were observed up to 35 days at weekly intervals for the appearance of symptoms. The observations on days for first symptom appearance, number of plants infected and type of symptoms produced were recorded. After 35 days of inoculation the youngest leaf of the plant was taken for further serological and molecular analysis.

RESULTS AND DISCUSSION

Identification of viruses associated with symptoms: *Begomovirus* specific primers *viz*. PALIc(5'ACNGGNAARACNATGTGGGC3') and PARIv (5'GGNAARATHTGGATGGA3') amplified a specific product of ~1280 bp (Fig. 4) in the muskmelon samples showing yellows and leaf curl symptoms that confirms the association of begomovirus with these symptoms. GBNV was found to be associated with necrosis symptoms of watermelon after the ELISA test.

Transmission of *Begomovirus* associated with yellows disease of muskmelons: Among these four methods, *Begomovirus* was successfully transmitted through whitefly. In whitefly-based transmission, symptoms were observed 11 days after inoculation (DAI), whereas cent per cent plants showed symptoms after twenty one days of inoculation (Table 1). Mechanically inoculated plants were found to be healthy even after one month of inoculation (Fig. 1). Viruliferous aphids that were fed on infected plants (Fig. 2) also did not produce any symptoms on healthy inoculated plants even after 30 days. Similarly, no symptoms were observed on the plants grown from the seeds collected from infected fruits even after four weeks of sowing (Table 1). In whitefly inoculated plants first symptoms initiated as chlorotic spots, later turns to mild puckering and yellow vein mosaic symptoms 14 DAI on young leaves that later on convert into

severe yellow vein mosaic symptom at 21 DAI and the whole leaf turned yellow/ bleached at 28 DAI. In some plants older leaves get curled downward at 14 DAI and these curled leaves turn completely yellow after 28 days of inoculation (Fig. 3). Presence of this *Begomovirus* in whitefly inoculated plants were further confirmed by *Begomovirus* specific primers PALIc and PARIv (Rojas et al 1993) that amplify *Begomovirus* specific band of ~1280bp in whitefly inoculated plants DNA (Fig. 4).

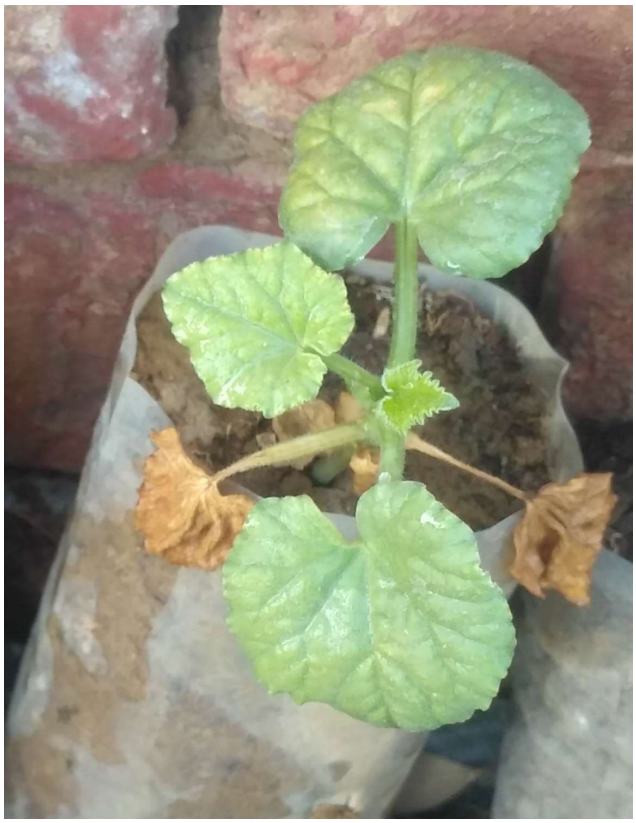

Fig. 1. Mechanically inoculated plant after 14 days of inoculation

Many workers reported transmission of different *Begomoviruses* through whitefly in various vegetable crops (Hidayat and Rahmayani 2007 and Ghanim et al 2007). Brown and Nelson (1985) reported a new whitefly transmitted *Begomovirus viz.* watermelon curly mottle virus infecting watermelon and lettuce. They tried to transmit this virus to various indicator plants through mechanical and whitefly inoculation and observed that mechanical transmission of virus from infected lettuce plant to indicator hosts did not occur, whereas isolates from watermelon produces symptoms on indicator plants *viz.* red kidney bean, big max pumpkin and zuchini squash plants. They also reported that virus isolates from both lettuce and watermelon were efficiently transmitted through whitefly to various indicator host plants. Similarly other workers also reported the transmission of *Begomovirus* by whitefly in different crop

Fig. 2. Aphids feeding on infected plants of the Muskmelon

Table 1. Transmission of major viruses infecting melons in Punjab

Inoculation method	First symptom appearance	% disease Incidence				Types of symptoms
		14 DAI/S	21 DAI/S	28 DAI/S	35 DAI/S	
Muskmelon cv. Pb. Sunheri ; Virus: *Begomovirus*						
Mechanical transmission	-	-	-	-	-	
Aphid transmission	-	-	-	-	-	
Whitefly transmission	11 DAI	60	100	100	100	Puckering, downward curling, severe yellows, intervenial chlorosis
Seed transmission	-	-	-	-	-	
Watermelon cv. Barmeri; Virus: *Groundnut bud necrosis virus*						
Mechanical transmission	-	-	-	-	-	
Aphid transmission	-	-	-	-	-	
Whitefly transmission	-	-	-	-	-	
Seed transmission	34 DAS	-	-	-	1	Necrotic lesion

(-) : No symptoms observed

plants (Mehta et al 1994, Rubinstein and Czosnek 1997 and Abudy et al 2010). Unlike the finding of this study, Lopez et al (2015) mechanically inoculated tomato leaf curl New Delhi virus to the different cucurbit crops.

Transmission of GBNV associated with necrosis in watermelon samples: For transmission studies in watermelon the GBNV seropositive plants showing necrosis on young leaves and stems were selected as inoculums for

Fig. 3. Symptoms produced by the whitefly transmission of *Begomovirus* associated with yellows disease of Muskmelon. 1) mild puckering and yellow vein mosaic symptoms on young leaf after 14 days of inoculation B) Yellow vein mosaic symptoms on young leaf after 21 days of inoculation C) Complete yellows symptom on leaf after 28 days of inoculation D) Leaf curl symptom after 14 days of inoculation E) Leaf curl symptom after 28 days of inoculation

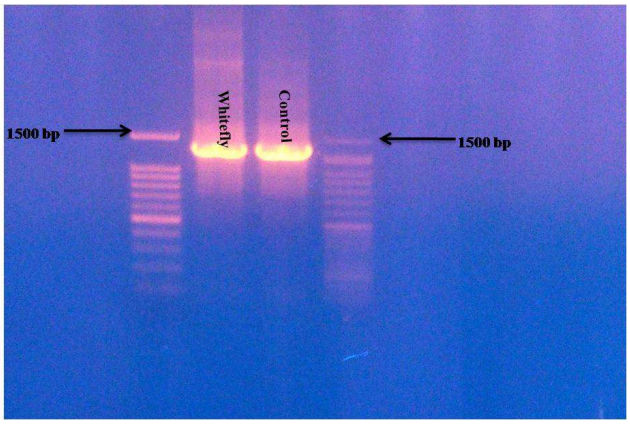

Fig. 4. PCR amplicons obtained from whitefly inoculated and positive sample of muskmelon with *Begomovirus* specific PALIc and PARIv primer pair. Single typical ~1280bp band in whitefly inoculated and positive sample identified the presence of *Begomovirus* in whitefly inoculated plant. Lane 1 in the gel contain 100bp DNA ladder (SimBio) and Lane 4 in the gel contain 50bp DNA ladder (NextGen Life Sciences)

Fig. 5. Necrotic lesion appeared on the seedling grown from infected seeds after 34 days of sowing

transmission studies. Among tested methods virus associated with necrosis showed very low per cent of transmission through seed. The seeds collected from infected fruits showed transmission up to one per cent only. No transmission could be established through mechanical, aphid, and whitefly (Table 1). Necrotic lesion type of symptoms (Fig. 5) appeared on seedlings after 34 days of sowing, whereas no symptoms appeared on the mechanically, whitefly and aphid inoculated plants even 30 days after inoculation. Serologically virus associated with necrosis symptoms was confirmed as GBNV.

In this study, we tried to transmit the virus causing necrotic symptom through mechanical, whitefly and aphid inoculation and were unsuccessful in transmitting the symptoms from diseased to the healthy plants. Low per cent of seed transmission could be due to the difference in the virus species that produced these necrotic symptoms on infected plant.

CONCLUSION

In muskmelon *Begomovirus* was found to be transmitted through whitefly and in watermelon GBNV has shown very low level of transmission through seed. So, in future this information can be used for evaluation of different insecticides for the effective management of these insect vectors that ultimately helps in the management of these viruses. Further studies can be designed to determine the total time taken by insect vectors for the transmission of viruses from diseased plant to healthy plants that will help in developing better spray schedule of insecticides for the effective management of insect vectors and viruses. Use of healthy seeds can also lead to effective management of GBNV in watermelon crop.

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Incidence of Fungal Wilt in Tomato and Characterization of Pathogen

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***Abstract*:** A survey work was carried out to determine the incidence of fungal wilt of tomato in three Southern districts of Karnataka *viz*. Bengaluru rural, Chikkaballapur and Kolar during the cropping season in 2019-20. Incidence of fungal wilt in these districts ranged between 8.68 to 13.03 per cent, with a mean incidence of 11.25%. Highest incidence of fungal wilt was observed in Chikkballapur district followed Kolar, whereas the lowest incidence was recorded in Bengaloru rural district. During the survey, symptoms of the disease observed was typical yellowing and vein clearing of lower leaves, stunting, necrosis, discoloration and wilting. The symptoms moved upwards with the gradual upward extension of the pathogen and discoloration of the vascular tissue of stems and roots and also the entire plant got affected and finally dried. Fungal wilt pathogen isolated on PDA was identified to be *Fusarium oxysporum* f. sp. *lycopersici* (Sacc.). The pathogen cultures could produce diverse colors and exhibited two types of conidia *i.e.* macro and micro conidia, could grow between 10^0C and 35^0C and produced abundant spores at 28^0C.

***Keywords*:** Tomato, Fungal wilt, Characterization, *Fusarium oxysporum*

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop grown throughout the world. It is native to South America, botanically similar to cherry tomato. Tomato is grown in Karnataka in an area of 0.60 lakh hectares, it ranks second in production and productivity (20.46 lakh tonnes and 34.10 tonnes/ha respectively) (Anonymous 2017). The fungal wilt of tomato is one of the severe diseases that affect the yield. Fungal wilt is caused by *Fusarium oxysporum* f. sp. *lycopersici* is known to cause severe economic losses in major tomato growing areas worldwide (Abdullah et al 2013). It is a soil born pathogen very destructive in causing 10 to 50 per cent yield loss in some tomato production areas (Ghazalibiglar et al 2016). It is very difficult to control fungal wilt of tomato, since the pathogen can progress within the vascular tissue by limiting the effectiveness of fungicides. Present study was executed towards survey of fungal incidence in major tomato growing districts of southern Karnataka *viz*. Bengaluru rural, Chikkaballapur and Kolar and to characterize the symptoms, extent of damage and the actual causal organism of fungal wilt.

MATERIAL AND METHODS

The present study on survey of fungal wilt disease on tomato in major tomato growing districts of South Karnatka, *viz*. Bengaluru rural (latitude: 13^0 05' 60.00" N and longitude: 77^0 13' 48.00" E), Chikkaballapur (latitude: 13^0 26' 6.43" N and longitude: 77^0 43' 40.33" E) and Kolar (latitude: 13^0 18' 12.16" N and longitude: 78^0 07' 45.01" E) was carried out. Fungal wilt disease incidence and crop loss were recorded in 14 to 17 villages (Table 1) of these districts with sample size of two plants in each field. The diseased samples were analyzed in the Department of Plant Pathology, College of Horticulture Bengaluru, under laboratory conditions during 2019-2020. Fungus infected stem and roots of tomato plants showing typical symptoms of wilt were collected, cut with the help of blade to identify *Fusarium* wilt symptoms in the tomato plants and the incidence of disease was expressed in per cent (Dhingra and Sinclair 1995).

The isolation of wilt pathogen (*Fusarium oxisporum*) of tomato was done from roots and stems which showed characteristic discoloration. The infected plant material was washed with tap water to remove the surface contaminants. One to two cm bits of diseased and healthy portion of roots and collar region of the plant was cut and removed. The bits having diseased portions were surface sterilized with sodium hypo chloride (1%) for 30 seconds, washed thrice with sterile distilled water. The surface sterilized bits were placed on sterile filter paper to remove excess moisture and then placed in sterile petri plates containing potato dextrose agar (PDA). The PDA medium was supplemented with streptomycin (30 mg L^{-1}), while pouring it into petri plates after sterilization (autoclaved at 1.05 kg/cm^2 for 20 minutes). Such

of the inoculated petri plates were kept in incubator at 27±1^{0}C and examined daily for mycelial growth. The fungi were purified by hyphal tip technique and pure culture was maintained on slants containing PDA (Rahimi et al 2019) and preserved at 5^{0}C in refrigerator for further studies. Sub culturing of the stock culture was done at an interval of 20 to 24 days.

The morphology of the fungus was studied from root and stems discoloration of infected tomato plants by sectioning and observing under microscope and also used 5-10 days old culture grown on potato dextrose agar medium by adopting slide culture technique (Rahimi et al 2019). The fungus had produced pure white to creamy white cottony colony on Potato Dextrose Agar surface. The colour of *Fusarium oxysporum* f. sp. *lycopersici*on on PDA medium varied between white, creamish white to cream, light pink to pink and light purple to violet as outlined by Nirmaladevi and Srinivas (2012). Septation, shape and colour of various morphology structures like mycelium, micro and macroconidia, chlamydospores, sporodochia etc. were recorded with the help of microscope to identify the pathogen.

RESULTS AND DISCUSSION

Incidence of fungal wilt in tomato: Disease incidence of fungal wilt of tomato was analyzed using systematic survey of symptoms and occurrence of wilt disease. Incidence of fungal wilt was found in all the three districts surveyed and ranged between 8.68 to 13.03 per cent (Table 1). The mean incidence of fungal wilt in three districts surveyed was 11.25 per cent. Disease incidence was maximum (13.03 %) in Chikkaballapur district followed by Kolar (12.05 %), and it was lowest in Bengaluru rural district (8.68 %). The fungal disease caused by *Fusarium*. *oxysporum* f. sp. *lycopersici* (Sacc) was observed during the cropping season in 2019 in these districts (Sayed farooq 2020). *Fusarium* wilt became a serious disease in many warmer areas, because causal organism of the disease, *Fusarium oxysporium* f. sp. *lycopersici* prefers 25-31^{0}C soil temperature for growth and development (Amini and Sidovich 2010). Gupta and Thind (2006) observed the increased soil temperature during summer to be the major factor for prevalence of *Fusarium* wilt in tomatoes grown under field and polyhouse having temperature 30^{0}C and above in mid hill of Himachal Pradesh. Continuous cropping of tomato round the year under polyhouse might be another reason for increased incidence of this disease, under polyhouse (Narender and Jitender 2014). Increase and spread of soil born disease especially fungal wilt is further high when a specific crop was grown continuously as reported earlier by (Charoenporn et al 2010).

Table 1. Incidence of *Fusarium* wilt of tomato observed in 3 districts of Karnataka during 2019-20

Bengaluru rural Latitude: 13^0 05' 60.00" N Longitude: 77^0 13' 48.00" E		Chikkaballapur Latitude: 13^0 26' 6.43" N Longitude: 77^0 43' 40.33" E		Kolar Latitude13^0 18' 12.16" N Longitude:78^0 07' 45.01" E	
Village	Disease incidence (%)	Village	Disease incidence (%)	Village	Disease incidence (%)
Marasandra	9.50	Marana halli	15.50	Pathand halli	13.50
Kadatanamale	10.50	Doddadasa halli	12.50	Rajendrahalli	8.50
Kampalingana halli	6.50	Bagalur	11.50	Marasana halli	11.40
Pura	7.40	Chimtamani	14.40	Hunegal	13.90
Kommasandra	10.40	Balagere	12.20	Doddapaila gurki	10.40
Ranganth pura	6.10	Shidalgatta	9.12	Mulabagalu	12.30
Meddena halli	8.40	Bagepalli	14.40	Srinivasapura	14.20
Vijaypura	7.30	Gudibande	14.30	Malur	12.50
Thindlu	10.40	Sadhahalli	12.20	Dodda kadatur	9.40
Gollahalli	9.11	Nandhi	16.50	Chavvena halli	14.11
Devanahalli	9.50	Kasaba	12.11	Masti	12.50
Mahadeva Kodigehalli	8.30	Mandikal	9.50	Dypasandra	12.40
Kadatenamele	11.90	Davappangudi	15.40	Perasena halli	11.30
Kranpalingona halli	6.30	Ammagarana halli	16.30	Jakkasandra	11.80
		Mulabagalu	9.30	Narasapura	13.30
		Huepagal	12.10	GaaliAnjaneya	9.14
		Marasasama halli	14.20	Perasenahalli	14.20
Mean	8.68	Mean	13.03	Mean	12.05
Over all mean			11.25		

Isolation, characterization and identification of pathogen: Infected roots and stems of tomato were cut in to small pieces with the help of razor blade and confirmed the presence of fungal wilt. Such infected samples were used for the isolation of the pathogen on PDA. Isolates causing fungal wilt on surface of potato dextrose agar produced diverse colors *i.e.* white, white to cream creamish, pink and light violet to purple and took 8 days to fully cover the petri plate. The two types of conidia *i.e.* macro and micro conidia, microconidia were aseptate, hyaline and oval to round in shape and macroconidia were 3 to 5 in number and they were septate, often blocked at tapered tip and somewhat thicker at upper third portion than in central portion (Table 2). The isolated cultures were characterized and identified to be similar to that of *Fusarium oxysporum* f. sp. *lycopersici* (Booth 1971, Brayford 1992).

Effect of temperature on, growth and sporulation of *Fusarium oxysporum* in vitro: The effect of various temperatures on growth and sporulation of *Fusarium* revealed that the fungus mycelium could grow between 10^{0}C and 35^{0}C (Table 3). The maximum mycelium growth of the pathogen was at 28^{0}C (85.0 mm), followed by 77.0 mm and 55.0 mm at 30^{0}C and 20^{0}C respectively. No growth was observed at 0^{0}C, 5^{0}C and 40^{0}C temperatures. The abundant sporulation was observed at 28^{0}C, and moderate sporulation was between 20^{0}C and 35^{0}C. However poor growth and sporulation was observed at 15^{0}C and there was no sporulation at 0^{0}C, 5^{0}C and 40^{0}C temperatures. Fayzalla et al (2008) observed maximum favorable temperature range for growth and sporulation of *Fusarium* wilt pathogen to be 25^{0}C - 30^{0}C. Sharma et al (2011) also reported for most favorable growth and sporulation of the *Fusarium* wilt pathogen, *Fusarium oxysporum* f. sp. *lycopersici* that causes wilt of tomato.

Table 2. Morphological characters of *Fusarium oxysporum* f. sp. *lycopersici*

Isolated wilt pathogen character	
Microconidia	Present
Macroconidia	Usually abundant
Sporodochia	Orange to brown colour and relatively common
Morphology	Thick and blunty pointed at their apex. The dorsal side is somewhat curved, but the ventral side is almost straight.
Size	Microconidia = 2.2-4.7 × 1.4-2.5 µm Macroconidia size = 23.0-38.0 × 2.7-5.4 µm
Development	Develop singly from phialides
Chlamydospores	Usually abundant and form relatively fast, requiring 3-5 week
Location	In hyphae and macroconidia
Morphology	Thick walled and globose
Appearance	Found singly, in chains
Size	8-10 µm in diameter

Table 3. Effect of temperature on growth and sporulation of *F. oxysporum* f. sp. *lycopersici*

Temperature (^{0}C)	Mean colony diameter in (mm) after 7 days of inoculation*	Sporulation*	Index
0	0.0	-	- :No sporulation
5	0.0	-	
10	15.00	-	
15	30.00	+	+:Poor sporulation
20	55.00	++	++:Moderate sporulation
25	70.00	+++	+++: Good sporulation
28	85.00	++++	++++:Abundant sporulation
30	77.00	+++	*Mean of three replication
35	56.00	++	
40	0.00	-	
CD (p=0.05)	2.34		

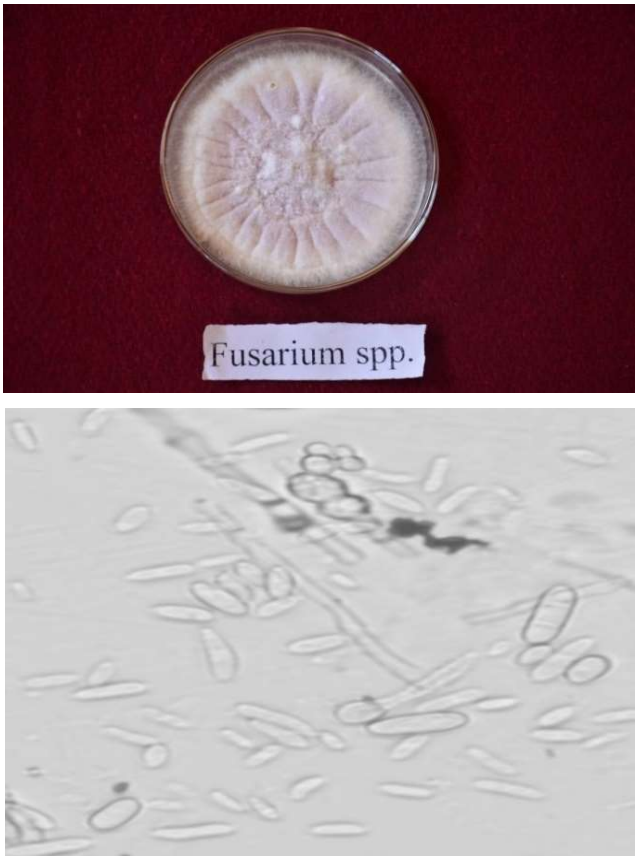

Fig. 1. Pure culture of *Fusarium* wilt fungi on PDA; mycelium and conidia of *F. oxysporum* f. sp. *lycopersici* (×40X)

CONCLUSION

The incidence of fungal wilt was highest in Chikkabalapur (13.30%), followed by Kolar (12.05 %) and Bangalore rural (8.08%). The fungus produced diverse colors and took 8 days for complete growth on potato dextrose agar plates. The fungus produced aseptate, hyaline and oval to round shaped microconidia as well as septate macroconidia. Fungus could grow between 10^{0}C and 35^{0}C and produced maximum mycelial growth at 28^{0}C (85.0 mm) on potato dextrose agar. The cultural and morphological identification showed that the pathogen was *Fusarium oxysporum* f. sp. *lycopersici*.

CONTRIBUTION OF AUTHOR

Sayed Farooq Mahboobi did surveying, isolation and characterization of the fungus. T.H. Shankarappa done conceptualization, analysis and write up, V. Devappa identified the disease and fungus and J.S. Arvinda Kumar reviewed and supervised the work.

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Epiphytic Lichens and Lichenicolous Fungi with New Records from Garhwal Region of Uttarakhand

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***Abstract*:** The study was conducted in an unexplored habitat of *Quercus* Forest of Uttarakhand Garhwal region to examine the Lichen and Lichenicolous fungi status of the area. The preliminary study reveals a total of 49 epiphytic lichens and nine lichenicolous fungi including two new records for India i.e., *Arthonia punctella, Epithamnolia pertusariae* and one new report to Uttarakhand State i.e., *Labrocarpon cannariensis*.

***Keywords*:** Chandrabadni, Lichenicolous fungi, Lichen diversity, Lichen taxonomy, New records, *Quercus* forest

Lichens are universally distributed organisms occurring in varied climatic conditions. Old growth Oak trees are of particular interest because they provide substrate for several organisms from several taxonomic groups, e.g., epiphytic lichens, bryophytes and many insects (Ek and Johannesson 2005, Jansson et al 2009). The study was conducted in unexplored dense *Q. oblongata* forest of Chandrabadni temple. In temperate zone, *Quercus* forests, are global hotspots of biodiversity and are considered as one of the most important habitats in a variety of ecosystems (Gough et al 2014). With increasing age, oak bark becomes more suitable for rare and threatened species and such trunks of old growth oak host a diverse lichen flora (Johansson et al 2009, Thor et al 2010). As texture, humidity and pH of bark provides favourable conditions that offers different types of niches to epiphytic lichens (Zedda 2002). Lichens population is important in determining impacts of disturbance on the forest structure and function. Lichens with cyanobacterial blue green symbionts, contribute significantly for forest nitrogen fixation. One of the first responses of lichen assemblages to increased nitrogen depositions is the reduction in oligotrophic lichens in favour of an increase in nitrophilous species (Pinho et al 2009), bringing about a general homogenization of the lichen vegetation (Liska and Herben 2008). Lichen diversity surveys enable estimating the effects of atmospheric pollution and other predictors in urban areas and remote environments (e.g., forest ecosystems), and in some cases, the synergistic effect of management (harvesting) and pollutants is detectable (Giordani 2007).

Lichens have been widely used for monitoring air pollution because they directly respond to the atmospheric conditions (Nimis et al 2002). Documenting the lichen population can help for assessment of future forest management on general forest health and biodiversity (Moning et al 2009, Svoboda et al 2010, Nag et al 2011). Lichen diversity rich forests are highly explored at present time while such habitats are needed to be conserved, however, there are many unexplored areas in Garhwal Himalayan region and one should focus on them. Besides overexploitation, lichen degradation by another fungus (Lichenicolous) is a major problem that can directly affect lichens' diversity by eliminating them. Lichenicolous fungi are the group of fungi that grow on Lichen thallus. They are especially adapted to the balanced association of fungal and algal organisms and together with their hosts they constitute a complex multi-biont system. The lichenicolous fungus infects the host lichen hyphae at different places and spreads mainly in the inter-hyphal matrix of the host. In recent years researchers shown interest in lichenicolous fungi as there is high possibility of finding new species and new records. This study shows the list of lichen and lichenicolous fungi occurring in the study site.

MATERIAL AND METHODS

Lichen samples were collected from Chandrabadni temple forest of Tehri district in Garhwal Himalaya, Uttarakhand. The area is in temperate zone at an altitude of about 1850-2245 m asl with minimum to maximum temperature ranges from 18°C to 31°C, the area receives adequate rainfall generally commencing from June and extending up to mid-September. Forest is dominated by

Quercus oblongata, Q. semecarpifolia with associated species like *Berberis* sp., *Rhododendron arboretum, Myrica esculenta*, *Pinus roxburghii* and some trees of *Cedrus deodara* etc. These climatic conditions are congenial for the growth of lichens in these broad-leaved forests.

Collected samples were cleaned and dried at room temperature. Morphological study was done using OLYMPUS SZ40 110AL2X WD28 stereo zoom microscope. Section was studied under OLYMPUS CX21 ILED FSI light microscope. The specimens were identified and authenticated through personal observations and available identification keys (Awasthi 1991; 2007). Chemical test K, I, KI, C, KC were applied for confirm identification of lichens.

RESULTS AND DISCUSSION

The present study was conducted in Chandrabadni Temple forest (*Q. oblongata*) to assess the diversity of epiphytic lichens and lichenicolous fungi. This unexplored forest range reveals nine lichenicolous fungi out of which two are new records for India (i.e., *Arthonia apotheciorum* and *Arthonia punctella*) The 49 epiphytic lichen species belonging to 14 families and 26 genera were observed. The eleven species belong to Lecanoraceae and Parmeliaceae, five from Physciaceae, Pertusariaceae and Ramaliniaceae. Hymeneliaceae, Verrucariaceae and Graphidaceae contains two, Caliciaceae, Chrysothricaceae, Cladoniaceae, Collemataceae, Stereocaulaceae and Teloschistaceae has only one specie (Table 1). The nine lichenicolous fungi belong to seven different families i.e., Arthoniaceae, Mycocaliciaceae, Corticaceae, Obryzaceae, Asterniaceae, Sclerotiniceae and Abrothalaceae (Table 2). The crustose taxa exhibit luxuriant growth in the area because they are under less environmental stress due to their micro structure. Out of 49 species 25 belongs to crustose group followed by foliose with 13 species and fruticose with nine species. Rich lichen diversity was observed in the forest because it is dominated by oak tress which provides best substrate for the growth of lichens. The lichen species diversity is reinforced by the exposure of tree stems to sunlight. As lichens are an important component of ecosystem and their diversity keeps the ecological process in a balanced state. Therefore, oak rich forests are of immense ecological significance and play an important role for providing suitable habitat to lichens.

New Records

1. *A. punctella* Nyl**.** Carroll. Nat. Hist. Rev. **6**: pp 533

Host: *Diplotomma alboatrum*

Distribution in India: Uttarakhand State

Taxonomy

Ascomata on thallus tissues, rarely on Ascomata, Ascomata arthonioid, Hypothecium dark greenish brown or brown, Ascospores soon becoming brown and warted, 12−17×5−6.5(7.5) µm; hymenium I+ blue; ascomata 0.07−0.22mm diam.

Material Examined: India, Uttarakhand, Tehri district, Chandrabadni Temple forest, 19°S 30°20'31" N 78°37'41" E 1480m asl. on *Diplotomma alboatrum*. Growing on *Cedrus deodara*. This species is a new record for India.

World Distribution: West region of Europe, Asia, (Turkey, Israel, Iran), North Africa and South America.

2. *Epithamnolia pertusariae* (Etayo and Diederich) Diederich and Sujia Comb. Nov.

≡ *Hainesia pertusariae* Etayo and Diederich **60**: 417 (1996)

Host: *Pertusaria sp*.

Distribution In India: Uttarakhand State

Taxonomy

Conidia needle-like, straight, 0(−1) septate, 14−22×1−5µm; conidiogenous cells vertically catenate; conidiomata disc-like with a raised margin, 80150µm diam; on Pertusaria sp. on bark.

Material examined: India, Uttarakhand, Tehri district, Chandrabadni Temple forest, 19°S 30°20'31" N 78°37'41" E 1480m asl. on *Pertusaria* sp., growing on *Quercus oblongata.* This species is a new record for INDIA.

World distribution: Northern France, Belgium and Netherland.

3. *Labrocarpon canariensis* (D. Hawksw.) Etayo and Pérez-Ortega, in Pérez-Ortega and Etayo Lichenologist **42**(3): 271 (2010)

≡ *Melaspilea canariensis* D. Hawksw., Lichenologist 14(1):84 (1982)

HOST: *Pertusaria* sp.

Distribution in India: Uttarakhand State

Taxonomy

Ascomata elongate, Ascomata simple, Ascus apex with a K/I+ blue apical dome (at least in upper part) or thick, outer gelatinized layer, Ascospores 17−20×6−8µm; ascomata 0.3−0.4×0.1−0.2mm.

Material examined: India, Uttarakhand, Tehri district, Chandrabadni Temple forest, 19°S 30°20'31" N 78°37'41" E 1480m asl. On *Pertusaria* sp. growing on *Q. oblongata*.

New report to Uttarakhand.

World distribution: Macronesia, Western Asia, South America, Australia.

The study inferred that the factors affecting the humidity regime of the forest also affected the epiphytic lichen species composition. Epiphytic lichen species diversity is affected by microclimatic conditions (air humidity, temperature, and light), and structural factors (canopy closure, vertical structure of the canopy, and shrub layer), both of which affect

Table 1. List of Epiphytic Lichens collected from Chandrabadni temple forest

Family	Lichen type	Substrate
Caliciaceae		
Buellia disciformis (Fr.) Mudd	Crustose	*Q. semecarpifolia* bark.
Chrysothricaceae		
Chrysothrix candelaris (L.) J.R. Laundon	Crustose	*Pinus* and *Q. oblongata* bark.
Cladoniaceae		
Cladonia macilenta Hoffm.	Squamulose	On soil
Collemataceae		
Collema flaccidum (Ach.) Ach	Foliose	*Q. semecarpifolia* bark.
Graphidaceae		
Graphis scripta (L.) Ach.	Crustose	*Q. semecarpifolia* bark.
Diploschistes cinereocaesius (Sw.) Vain	Crustose	*Berberis* and *Q. semecarpifolia* bark.
Hymeneliaceae		
Aspiecelia cineria (L.) Korb	Crustose	On rock.
Hymenelia lacustris M. Choisy	Crustose	On rock.
Lecanoraceae		
Lecanora achroides Vain.	Crustose	*Q. oblongata* bark.
L. allophane Nyl. [*L.subfusca* Mull. Arg.]	Crustose	On rock
L. argentata (Ach.) Malme	Crustose	*Q. semecarpifolia* bark.
L. chlarotera Nyl.	Crustose	*Q. semecarpifolia* bark.
Lcircumborealis (Brodo and Vitik)	Crustose	*Q. oblongata* bark.
L.gangaleoides Nyl.	Crustose	*Q. semecarpifolia* bark.
L. pulcaris (Pers.) Ach	Crustose	*Q. semecarpifolia* bark.
L.strobilina (Sprengel) Kieffer	Crustose	*Q. oblongata* bark.
Lecidella euphoria (Florke) Hertel	Crustose	*Q. semecarpifolia* bark.
Lecanora dispersa (Pers.) Florke	Crustose	*C. deodara* and *Q. oblongata* bark.
Lecanora fructosa	Crustose	*C. deodara* and *Q. oblongata* bark.
Parmeliaceae		
Evernia prunastri (L.) Ach.	Fruticose	*Q. semecarpifolia* bark.
Flavoparmelia caperata (L.) Hale	Foliose	*Q. semecarpifolia* bark.
Hypotrachyna cirrhata (Fr.) Divakar, et.al. [*Everniastrum cirrhatum* (Fr.) Hale ex Sipman	Foliose	*Q. semecarpifolia* bark.
H. nepalense (Taylor) Divakar, et.al. [*Everniastrum nepalense* (Taylor) Hale ex Sipman]	Foliose	*Q. oblongata* bark.
Parmotrema austrosinense (Zahlbr.) Hale	Foliose	*Q. semecarpifolia* bark.
P. latissimum (Fee) Hale	Foliose	*Q. oblongata* bark.
P. perlatum (Hudson) M.Choisy	Foliose	*Q. oblongata* bark.
P. praesorediosum (Nyl.) Hale	Foliose	*Q. semecarpifolia* bark.
Usnea eumitrioides Motyka	Fruticose	*C. deodara* and *Q. oblongata* bark.
U. florida (L.) Weber ex F.H. Wigg	Fruticose	*Q. semecarpifolia* bark.
U. orientalis Motyka.	Fruticose	*Q. semecarpifolia* bark.
Pertusariaceae		
Pertusaria albescens (Huds.) M. Choisy & Werner	Crustose	*Q. semecarpifolia* bark.
P. alpina Hepp ex Ahles	Crustose	*Q. oblongata* bark.
P. punctata Nyl.	Crustose	*C. deodara* and *Q. semecarpifolia* bark.
Pertusaria sp. DC	Crustose	*Q. oblongata* bark.
Verseghya thysanophora (R.C. Harris) S.Y. Kondr [*Lecanora thysanophora* R.C. Harris.]	Crustose	*Q. oblongata* bark.
Physciaceae		
Heterodermia himalayensis (D.D. Awasthi)	Foliose	*Q. oblongata* bark.
Phaeophyscia endococcina (Korb) Moberg	Foliose	*Q. semecarpifolia* bark.
P. hirsute (Mereschk.) Essl.	Foliose	*Q. semecarpifolia* bark.
Physcia caesia (Hoffm.) Furnr.	Foliose	*Q. semecarpifolia* bark.
P.sorediosa (Vain.) Lynge	Foliose	*Q. oblongata* bark.
Ramalinaceae		
Bacidina suffuse (Fr.) A. Schneider	Crustose	*Q. semecarpifolia* bark.
B. phacodes (Korb.) Vezda	Crustose	*Q. semecarpifolia* bark.
Ramalina farinacea (L.) Ach.	Fruticose	*Berberis* and *Q. oblongata*.
R. sinensis Jatta	Fruticose	*Q. semecarpifolia* bark.
Ramalina sp. Ach.	Fruticose	*Berberis* bark
Stereocaulaceae	Leprose	On rock.
Lepraria incana (L.) Ach.		
Teloschistaceae	Crustose	On rock
Blastenia furfuracea (H.Magn.) Arup, Sochting and Froden. [*Caloplaca furfuracea* H. Magn.]		
Verrucariaceae	Fruticose	On rock.
Dermatocarpon miniatum (L.) W. Mann	Fruticose	On rock.
D.vellereum Zschacke		

Table 2. Lichenicolous fungi from Chandrabadni temple forest

Lichenicolous fungi	Host lichen	Substrate
Arthoniaceae		
Arthonia apotheciorum (A. Massal) Almq.	*Lecanora dispersa*	*Q. oblongata*
Arthonia punctella Nyl. Carroll. Nat. Hist. Rev.	*Lecanora dispersa*	*C. deodara*
Mycocaliciaceae		
Chaenothecopsis tigillaris Acta Soc. Fauna Fl. Fenn	*Lecanora fructosa*	*C. deodara*
Corticiaceae		
Erythricium aurantiacum (Lash) D. Hawksw. And A. Henrici.	*Lecanora fructosa*	*Q. oblongata*
Obryzaceae		
Intralichen lichenum (Diederich) D. Hawksw. And M.S. Cole.	*Heterodermia himalayensis* *Ramalina* sp.	*Q. oblongata,* *Berberis* sp.
Asterinaceae		
Labrocarpon canarensis (D. Hawksw.) Etayo and Perez−Ortega	*Pertusaria sp.*	*Q. oblongata*
Abrothallaceae		
Lichenoconium erodens M.S. Christ and D. Hawksw Persoonia.	*Physcia caesia*	*Q. oblongata*
L. pyxidatae (Oudem) Petrak et H. and Sydow.	*Parmotrema arnoldii*	*Pinus roxburghii*
Sclerotiniceae		
Epithamonolia pertusariae	*Pertusaria* sp.	*Q. oblongata*

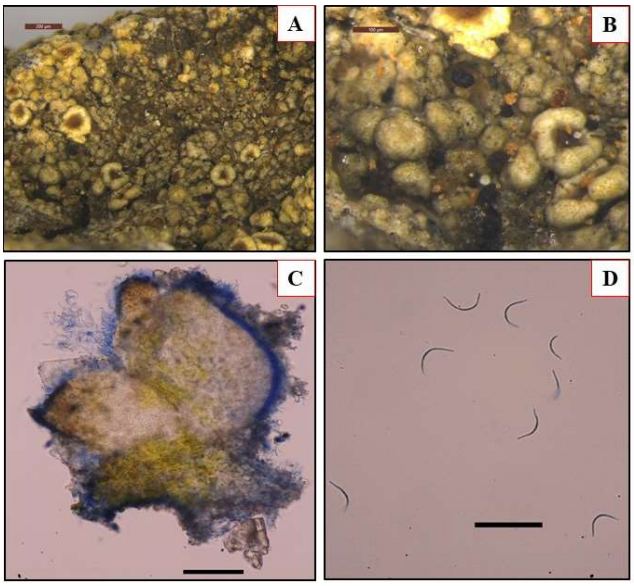

Fig. 1. Photo plate showing infected sample of *Pertusaria* lichen A. *Epithamnolia* Habitat B. Apothecia on host thallus C. Apothecial Section Bar 50 µm D. Ascospores Bar 25 µm

the microclimate in the stand. Furthermore, lichen species distribution may affect by landscape variables in addition to substrate availability, e.g., forest openness and landscape composition (Juriado et al 2003, Bolliger et al 2007). Collection of sources (wood, bark, grass) by local people impact the microclimatic conditions of forest. Villagers collect leaves by climbing tree on daily basis that affect the diversity of epiphytic lichens and the regeneration of their broken thallus. The topographic variables, such as elevation, convexity, slope, nutrients etc. were the most important factors that help in explaining the composition of epiphytic lichen species in forest. Two important macroclimatic factors, temperature and humidity, were clearly identified among the factors influencing the composition of the epiphytic lichen community. Increased light penetration increases the temperature in the stand, altering the epiphytic lichen composition due to the lower humidity (Sevgi et al 2019). Out of 49 lichen species nine are infected and the fungus which grows on these lichens is called lichenicolous fungus. *Lecanora* genus is highly infected, as four different types of lichenicolous fungi are degrading the *Lecanora* species.

CONCLUSION

Chandrabadni oak forest is a rich reservoir of epiphytic lichens on account of its luxuriant forest ecosystem with pollution free environment. Although the diversity of epiphytic lichens is often affected by various biotic and abiotic factors but nonetheless, this preliminary study on the dominance and diversity of epiphytic lichens certainly opens new horizon of lichen study in relatively less disturbed areas on a larger scale.

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Stage-Specific Feeding Potential and Preference of Predatory Mite *Neoseiulus longispinosus* (Evans) (Acari: Phytoseiidae) on Spider Mite *Tetranychus truncatus* Ehara

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***Abstract*:** *Tetranychus truncatus* Ehara is an important pest of a number of important agricultural and horticultural crops and is mainly prevalent in the southern Indian states of Karnataka, Tamil Nadu and Kerala. The pest is very often associated with predatory phytoseiid mite, *Neoseiulus longispinosus* (Evans), on almost all crops. Its ability to feed and preferred prey stage were determined under laboratory conditions of 23°C to 28°C and 75–80% RH. The larva was the non-feeding stage of the predator but protonymphs and deutonymphs showed comparable preferences for prey mite eggs and larvae, adult predators preferred more prey mite eggs. The predatory mite protonymph ingested 2.30 eggs, 2.70 larvae, 2.00 nymphs of prey mite and did not consume the adult stage. Deutonymph of the predator, consumed 6.60 eggs, 6.80 larvae, 4.70 nymphs and did not feed on the adult stage of the predatory mite. Adult female predator unlike its immature stages consumed 121.20 eggs, 144.30larvae, 94.70 nymphs and 36.20 adults of *T. truncatus* in the entire life span.

***Keywords*:** *Tetranychus truncatus*, *Neoseiulus longispinosus*, Feeding preference, Feeding potential, Phytoseiids

The most significant phytophagous family, the Tetranychidae, is thought to cause significant harm to cultivated crops by directly feeding on them thus reducing photosynthetic activity, causing defoliation, and lowering the economic yield (Gorman et al 2002). *Tetranychus truncatus* Ehara was first described from mulberry in Japan. It is well distributed in the Asiatic region attacking major crops like cotton, brinjal, peach, papaya and cassava *etc*. (Sakunwarin et al 2003). In India Spider mite *Tetranychus truncatus* was recorded from the northwestern Himalayan region of Jammu, Kashmir and Himachal Pradesh in 1983 on *Dahlia* sp. From Karnataka, it was described as a developing pest on domesticated and wild species of mulberry (Srinivasa et al 2012) and was reported as a serious pest of vegetable crops in Kerala (Binisha and Bhaskar 2013, Bennur et al 2015). The use of various acaricides to control spider mites has a number of unfavorable effects, including pesticide resistance, pesticide residues on crops, environmental risks, health risks, *etc*. (Roy et al 2011). Field populations of *T. truncatus* have reportedly become resistant to relatively new acaricides such as spiromesifen and fenazaquin (Bachhar et al 2019). It is challenging to control this phytophagous pest with common acaricides, so finding alternatives such as biological control to adequately manage this pest has become essential.

Phytoseiid mites are well known natural enemies of phytophagous mites on cultivated and wild plants in a variety of habitats. They have high reproductive potential, rapid rate of development and equivalent to their prey number allowing them to respond numerically to increased prey density, and can easily be mass-reared (Hoy 2011). Phytoseiid mites are effectively utilized as biocontrol agents in IPM programs in a variety of agricultural systems due to their great predatory potential. *Neoseiulus longispinosus*(Evans) a type II phytoseiid predatory mite has drawn significant interest in Asian nations as a possible biocontrol agent of spider mites of *Tetranychus* spp. There are 189 phytoseiid mite species reported from India (Gowda 2009) and over 2700 species worldwide (Demite et al 2017). As they are widely distributed in India and proved to be an effective predator of tetranychid mites since 2010, *N. longispinosus* has received more attention in the management of spider mites in the Asian continent. It can develop on many tetranychid species belonging to the genus Tetranychus, Eutetranychus, and Oligonychus (Nusartlert et al 2011). The preference and feeding potential of *N. longispinosus* on *T. truncatus* has not been systematically studied across the world including the Indian subcontinent. The present study was aimed at investigating the stage preference and feeding potential of the predatory mite *N. longispinosus* on its prey mite *T. truncatus.*

MATERIAL AND METHODS

Maintenance of prey mite culture *T. truncatus*: The

culture of prey mite, *T. truncatus* was maintained on excised mulberry leaves placed abaxial side up over wet foam sheets in plastic trays under laboratory conditions of temperature 23±1°C-28±1°C and 75-80% RH. The foam sheets were kept moist by regular watering to maintain the freshness of mulberry leaves or succulence. The dried or exhausted mulberry leaves were replaced with fresh leaves in every 5-6 days.

Maintenance of predatory mite culture *Neoseiulus longispinosus*: Stock culture of the predatory mite *N. longispinosus* was maintained on spider mite infested French bean plants in the polycarbonate house. The predatory mite nucleus culture was subsequently maintained in the lab using French bean leaves that had been infested with spider mites. Over damp foam sheets, predator-infested leaves were arranged in plastic trays and to stop the predatory mites from escaping, the foam sheet was maintained wet by watering the trays regularly.

Feeding preference of predator active stages on life stages of *Tetranychus truncatus*: In order to estimate predatory mite preference for individual life stages of the prey mite, a known number of each of the life stages of the prey mite (egg, larva, protonymph, deutonymph and adult) were offered together on fresh mulberry leaf bits of 2 cm^2 placed abaxial side up on wet foam sheets in plastic trays of 12″X10″ dimension. To each leaf bit known number of each life stage of prey mite was transferred. Later one freshly hatched neonate larva of the predatory mite was introduced onto each leaf bit and the number of prey stages consumed by the predatory mite was recorded. Accordingly, two each of the egg, larva, protonymph, deutonymph and adult prey stages were offered to the larval stages of the predatory mite, likewise three each of the above prey stages were offered to the predatory protonymph stages, five each to the predatory deutonymph and ten each to a female adult stage predatory mite. Thirty replications for the predatory immature stages and ten replications for the adult predatory mite were maintained. Observations were recorded at 3 h intervals for the number of prey stages consumed by the immature predator and at 12 h intervals for the number of prey stages consumed by the adult predator.

Feeding potential of predator active stages on life stages of *T. truncatus*: The experiment was conducted to know the maximum number of prey mites a predatory mite can consume. To achieve this, the predatory mite was given distinct prey life stages, including eggs, larvae, nymphs (protonymph + deutonymph), and adults, from the beginning of its larval stage to the end of its adult stage. The number of prey life stages consumed was recorded. For comparison, a treatment was also run combining all four stages of the prey mite. On each mulberry leaf bit, one neonate larva of the predatory mite was transferred. The predatory mite stages were allowed to feed on prey mites during their developmental stages and at adulthood till their natural death. For the protonymphal stages of the predatory mite, six prey eggs/larvae/nymphs/adults were offered in the first four treatments and two individuals of each prey stage were offered together in the fifth treatment. Likewise, for the deutonymphal stage of the predatory mite, ten prey eggs/larvae/nymphs/adult prey mites were offered in the first four treatments and three individuals of each stage were offered together in the fifth treatment. For the female adult predatory mite, twenty-five prey eggs/larvae/nymphs/adults were offered separately in the first four treatments and five individuals of each stage were offered together in the fifth treatment. The experiment was designed in CRD with ten replications. Observations on the number of each of the prey stages consumed by the predatory mite in its protonymphal, deutonymphal and adult stages were recorded at 24h intervals till its natural death. At each observation, the dead preys were removed and replaced by the fresh prey to make up the number as in the first instance (from the stock culture) to ensure the continuous availability of prey for feeding by the predator.

Statistical analysis: Prey consumption data by predatory mite active stages was subjected to analysis using IBM SPSS Statistics 23 software followed by Tukey's HSD test. With the data obtained for each stage of the predator, the per cent consumption was calculated using the (Jyothis and Ramani 2019)

$N_e/N_0 X\ 100$

Where, N_e = Number of prey stages consumed, N_0 = Number of prey stages offered

RESULTS AND DISCUSSION

Feeding preference of predator active stages on life stages of *T. truncatus*: The predatory mite larva in the present study did not consume any prey till it moulted into the protonymphal stage. Similar predator larval non-feeding behaviour was observed by Kadu (2007) and Rao et al (2017). Protonymph of *N. longispinosus* consumed a mean number of 1 prey egg, 1.12 larvae, 0.58 protonymphs and 0.29 deutonymphs. No adult mites were consumed during its life period of 17.28 h. An equal feeding preference for egg and larval stages of prey mite with a mean consumption rate of 33 and 37%, followed by protonymphal stage (19%) and deutonymphal stage (9%) of the prey mite was observed. The predator deutonymph consumed 1.70 prey eggs, 1.58 larvae, 0.83 protonymphs, 0.48 deutonymphs and 0.12 adults of prey mite in its life span of 22.08 h, which indicated

its preference equally for egg and larval stage of the prey mite accounting for a mean corresponding consumption of 34 and 31%, followed by 16% protonymph, 9% deutonymph and 2% adult prey consumption. Each adult female predatory mite consumed 3.55 prey eggs, 1.85 larvae, 1.80 protonymphs, 1.35 deutonymphs and 0.10 adults, exhibiting a preference for the egg stage of prey, *T. truncatus* with a consumption pattern of 71% eggs, followed by 37% larvae, 36% protonymph and 27% deutonymph stage and showed least preference for the adult stage of the prey mite (2%) (Table 1). Ahn et al (2009) and Farazmand et al (2012), observed that adult predatory mite, *N. californicus* on *T. urticae* consumed more eggs than other prey stages, which is consistent with the current findings. Jyothis and Ramani (2019), also reported that predator *N. longispinosus* preferred *T. neocaledonicus* eggs to larvae, nymphs, and adults, respectively. Kasap and Atlihan (2010) examined the consumption rate and functional response of the predatory mite *Kampimodromus aberrans* with *T. urticae* and reported that the predatory mite consumed a relatively higher number of larvae followed by eggs, protonymphs, and deutonymphs with the consumption of 3.27 eggs, 3.78 larvae, 1.86 protonymphs, and 0.60 deutonymphs, respectively which is in contrast to the present findings where predator consumed more number of egg stages of prey mite of *T. truncatus* followed by larval and nymphal stages.

Feeding potential of predator active stages on life stages of *T. truncatus*: The daily feeding potential of female adult predator on the four life stages of *T. truncatus* prey mites (egg, larva, nymph, and adult) when provided separately or collectively was examined (Table 2). On the first day, the predator consumed 7.2% of eggs with a mean consumption of 1.8 individual eggs, 20.4% of larvae with a mean consumption of 5.1 individuals, 10 % of nymphs with a mean consumption of 2.5 individuals, 1.2% of adults with a mean consumption of 1.4 individuals. On day 8th the predator consumed 22.8% eggs, 24% larvae, 14.8% nymphs, 6% adults and 20% of mixed stages with a mean consumption of 5.7, 6.0, 3.7, 1.5 and 5.0 individuals, respectively. On day 15th predator consumed 32.5% eggs, 26.8% larvae, 14.8% nymphs, 8% adults and 24.4% of mixed stages with a mean consumption of 8.1, 6.7, 3.7, 2.0 and 5.6 individuals, respectively. On day 22nd predator consumed 25% of larvae, 17.2% of nymph, 6.2% of adults and 21.2% of mixed stages with mean consumption rates of 6.3, 4.3, 1.6 and 5.3 individuals, respectively. The predator ceased feeding entirely on the 29th day. Ahn et al (2009) and Canlas et al (2006) recorded greater *T. urticae* prey consumption of per day, by predatory mite, *Neoseiulus californicus*, much higher than the present study. The difference in predator and prey species in these studies may be attributed to the variations in prey consumption. Singh and Singh (2018) reported that *Amblyseius indicus* consumed 6.13, 2.57 and 1.41 eggs, larvae and adults of the prey mite, *Tetranychus neocaledonicus* in 24 h, respectively, while, *Amblyseius tetranychivorus* correspondingly consumed 5.82, 2.24 & 1.18 eggs, larvae and adults of the prey mite. Eggs and larval consumption by the adult female predators of *A. indicus* and

Table 1. Feeding preference of life stages of predatory mite, *Neoseiulus longispinosus* for life stages of prey mite *Tetranychus truncatus*

Feeding stages of predatory mite	Prey mite stages offered together	Mean±S.E.	N_e/N_o
Protonymph (lived for 17.28 h)	Egg	1.00 ± 0.16^{cd}	0.33 ± 0.05^{cd}
	Larva	1.12 ± 0.12^{d}	0.37 ± 0.04^{d}
	Protonymph	0.58 ± 0.13^{bc}	0.19 ± 0.04^{bc}
	Deutonymph	0.29 ± 0.08^{ab}	0.09 ± 0.02^{ab}
Deutonymph (lived for 22.08 h)	Egg	1.70 ± 0.18^{c}	0.34 ± 0.03^{c}
	Larva	1.58 ± 0.17^{c}	0.31 ± 0.03^{c}
	Protonymph	0.83 ± 0.16^{b}	0.16 ± 0.03^{b}
	Deutonymph	0.48 ± 0.12^{ab}	0.09 ± 0.02^{ab}
	Adult	0.12 ± 0.07^{a}	0.02 ± 0.01^{a}
Adult (in 24 h)	Egg	3.55 ± 0.26^{c}	0.71 ± 0.05^{c}
	Larva	1.85 ± 0.21^{b}	0.37 ± 0.04^{b}
	Protonymph	1.80 ± 0.18^{b}	0.36 ± 0.03^{b}
	Deutonymph	1.35 ± 0.22^{b}	0.27 ± 0.04^{b}
	Adult	0.10 ± 0.06^{a}	0.02 ± 0.01^{a}

For each feeding stage of the predator, values with the same alphabetical superscript within the column are not statistically significant @ P=0.01

Table 2. Daily feeding potential of predatory adult *Neoseiulus longispinosus* on life stages of prey *Tetranychus truncatus*

Days	Single prey stage offered				All prey stages offered together				
	Egg	Larva	Nymph	Adult	Egg	Larva	Nymph	Adult	Total
Day 1	1.8 (10) (7.2 %)	5.1 (10) (20.4 %)	2.5 (10) (10%)	0.3 (10) (1.2 %)	0.5 (2%)	0.8 (3.2%)	0.1 (0.4%)	0	1.4 (10) (5.6%)
Day 8	5.7 (10) (22.8 %)	6.0 (10) (24 %)	3.7 (10) (14.8 %)	1.5 (10) (6%)	1.3 (5.2%)	1.8 (7.2%)	1.2 (4.8%)	0.7 (2.8%)	5.0 (10) (20%)
Day 15	8.1 (8) (32.5%)	6.7 (10) (26.8%)	3.7 (10) (14.8%)	2.0 (10) (8%)	1.4 (5.6%)	2.1 (8.4%)	1.2 (4.8%)	0.9 (3.6%)	5.6 (10) (24.4%)
Day 22	0 (4)	6.3 (8) (25%)	4.3 (10) (17.2%)	1.6 (7) (6.2%)	1.0 (4%)	1.9 (7.6%)	1.6 (6.4%)	0.9 (3.6%)	5.3 (8) (21.2%)
Day 29	0	0 (1)	0 (1)	0 (2)	0	0	0	0	0 (1)

*Figures in the parenthesis indicate the total number of female predatory mites alive out of 10 replicates over time and the per cent consumption

Table 3. Feeding potential of different life stages of the predatory mite, *Neoseiulus longispinosus* on life stages of prey mite, *Tetranychus truncates* (Mean±S.E.)

Feeding stages of predatory mite	Single prey stage offered				Prey stages offered together			
	Egg	Larva	Nymph	Adult	Egg	Larva	Nymph	Adult
Protonymph	2.30±0.39^{b*}	2.70±0.33^{b}	2.00±0.21^{b}	0	0.90±0.23^{a}	1.00±0.25^{a}	0.40±0.22^{a}	0
Deutonymph	6.60±0.97^{b}	6.80±0.67^{b}	4.70±0.36^{b}	0	1.30±0.39^{a}	2.20±0.41^{a}	0.78±0.24^{a}	0
Adult (Life period)	121.20±9.88^{b}	144.30±21.82^{b}	94.70±5.18^{ab}	36.20±4.67^{a}	28.30±3.94^{ab}	41.00±4.06^{b}	24.50±3.37^{ab}	13.40±2.53^{a}
Total	130.10±10.15^{b}	153.80±21.56^{b}	101.40±5.45^{b}	36.20±4.67^{a}	30.50±4.07^{ab}	44.20±4.18^{b}	25.68±3.28^{ab}	13.40±2.53^{a}

Mean values superscripted by the same letter within the row are not significantly different @ p=0.01

A. tetranychivorus was comparable to the number consumed in the present study.

Protonymph of predator had the potential to consume, on average 2.30 eggs, 2.70 larvae, 2.00 nymphs, when offered them separately and 0.90 eggs, 1.00 larvae and 0.40 nymphs, when offered all the prey stages together. The deutonymph consumed, on average 6.60 eggs, 6.80 larvae, 4.70 nymphs & no adult stage, when offered them separately and 1.30 eggs, 2.20 larvae, 0.78 nymphs when offered together in its life period. The, adult female predator during its living period consumed 121.20 eggs, 144.30 larvae, 94.70 nymphs, 36.20 adults of the prey when offered separately and 28.30 eggs, 41.00 larvae, 24.50 nymphs and 13.40 adults when offered as mixed stages. The predatory mite female from its protonymphal stage to the end of its adult stage had the potential of consuming 130.10 eggs, 153.80 larvae, 101.40 nymphs, and 36.20 adults of prey mite when offered separately (no-choice), and 30.50 eggs, 44.20 larvae, 26.10 nymphs, and 13.40 adults when all prey stages were offered as mixed (with choice) (Table 3). Facundo and Raros (2005) observed that *N. longispinosus* consumed 292 eggs of *T. truncatus* in its life span of 29 days. It is possible that the different survival periods of predators may be the cause for variation in the number of eggs consumed in these studies. Sanchit and Shukla (2016) recorded that *N. longispinosus* consumed substantially less *T. urticae* eggs , adults , and mixed-stages , than reported in the current study. Negm et al. (2014) reported that the predators, *Cydnoseius negevi* and *Neoseiulus barkeri* consumed 270 and 205 *Oligonychus afrasiaticus* preys in their lifetime which was significantly more than what was seen in the current study, may be because of change in the predator and prey species. Sathish et al. (2019) reported the predator *Neoseiulus baraki* consumed 553 *Aceria guerreronis* prey overall during its whole life span, the higher number may be because of the smaller size of eriophyid mites.

CONCLUSION

Protonymph and deutonymph of predator equally preferred the egg and larval stages while adult predators only preferred the egg stage of prey mite. The adult female predator had the potential of consuming 121.20 eggs or 144.30 larvae or 94.70 nymphs or 36.20 adults of *T. truncatus* during the course of its whole life. The data generated from the present study will be helpful to plan the biocontrol program against *T. truncatus*.

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Odonate Diversity in Paddy Fields and Environs of Madakkathara Grama Panchayath, Thrissur, Kerala, India

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***Abstract*:** The diversity of odonates was documented from Madakkathara Grama Panchayath in the Thrissur District of Kerala state in southern India. Field surveys which were conducted from December 2018 to November 2019 recorded 47 odonates, including 32 species of dragonflies (Anisoptera) and 15 species of damselflies (Zygoptera). Among dragonflies, the family Libellulidae dominated with 30 species, while Coenagrionidae with 9 species were dominant among damselflies. The 25.68% of the odonates in Kerala and 22.49% of the odonates in the Western Ghats were represented in the odonate diversity of the Madakkathara Grama Panchayath. The migratory species *Pantala flavescens* dominated the count, especially around the monsoons.

***Keywords*:** Anisoptera, Zygoptera, Western Ghats, Endemic, Species inventory

The order Odonata, which comprises dragonflies and damselflies, is one of the most fascinating insect groups due to their amphibious life history, relatively short generation time, high trophic position, and diversity. They are composed of primitive predatory insects, whose origins date back to the Permian period (Grimaldi et al 2005). Globally, there are over 6376 identified odonate species (Paulson et al 2022), of which 493 species are seen in India, 209 in the Western Ghats, and 183 in Kerala. These 183 species of odonates include 70 Western Ghats endemics, belonging to 87 genera under 2 suborders and 14 families (Nair et al 2021, Sadasivan et al 2021, Vijayakumaran et al 2022).

The order Odonata forms the apex predators in the freshwater ecosystems, and hence their diversity in rice fields from different parts of the country has been studied. Some notable works on paddy fields odonates in India include: Anbalagan et al (2013) have recorded 23 species of dragonflies and 12 species of damselflies from rice and vegetable fields in Tiruvallur district of Tamil Nadu, India; Arulprakash et al (2017) have recorded 19 species of odonates from rice fields of five major rice-growing areas of Pattukkottai, Thanjavur district in Tamil Nadu; A total of 44 species (30 dragonflies and 14 damselflies) belonging to 33 genera and eight families were recorded from the Kole Wetlands, central Kerala, India by Chandran et al (2021); 66 species were documented from Kattampally wetlands, Kannur, Kerala (Rodrigues et al 2022); Gunathilagaraj et al (1999) studied the odonate diversity in the rice fields of Coimbatore and recorded 16 species of odonates from the study area; A total of 12 species of Odonata under three families and 12 genera were collected and identified during the survey in the irrigated rice ecosystem of Madurai, Tamil Nadu by Kandibane et al (2005); Palot et al (2005) studied the odonate diversity of rice field habitat in Palakkad district, Kerala and recorded 21 species under 18 genera of 5 families; Rohmare et al (2016) investigated the diversity and population dynamics of odonata in the rice-growing area of Central Gujarat; and Talmale and Kulkarni (2003) collected 19 taxa from 17 genera and 5 families from the paddy fields of Bhandara district, Maharashtra.

This study focuses on the paddy fields of Madakkathara Grama Panchayath (MGP). Madakkathara village is in the Thrissur taluk of Thrissur district in Kerala, India. The area is located between 10° 33' 0.00" N- 10° 36' 0.00" N and 76° 15' 0.00" E- 76° 18' 0.00" E and has an area of 21.59 sq. km (Fig. 1). Even with its proximity to the city, MGP is an agriculturally intense place with a good area of land under cultivation. The intricate system of irrigation canals and related tanks, village ponds, and paddy fields in MGP offers promising odonate habitats. But the changes in land use practices, which mainly include the turning of agroecosystems like paddy fields into nurseries, housing plots, and fields for growing other crops like coconut, mixed cropping, etc, are seen inferred as a threat to local odonate diversity.

MATERIAL AND METHODS

Field surveys were conducted from December 2018 to November 2019 in the paddy field agroecosystems of

Madakkathara Panchayath, Thrissur from December to February (winter- W), March to May (summer- S), June to August (southwest monsoon- M1), and September to November (northeast monsoon- M2). Visual encounter surveys (VES) were done for adult odonates between 0900 and 1300 hrs to document them from the paddy fields and their adjoining irrigational canals. Odonates were not collected but were photographed using a Nikon COOLPIX P900 and a Nikon D5600 DSLR camera with a 70-300mm lens. Species identification was done using field guides (Subramanian 2009, Kiran and Raju 2013). The scientific names are adopted from the revised nomenclature by Kalkman et al (2020). The odonates observed during the study period were categorised into four groups based on their relative abundance modified from Adarsh et al (2014). Accordingly, those species which were sighted 75-100% of the survey days were categorised as 'Very Common' (VC), 50-74% as 'Common' (CO), 25-49% as 'Not Rare' (NR), and 'Rare' (RA) for those that were sighted less than 25% of the field days. The data analysis was done with the help of PAST software (Sivaruban et al 2020).

RESULTS AND DISCUSSION

In the study, we documented 47 species of odonates (Table 1), which included 32 species of Anisoptera (Dragonflies) and 15 species of Zygoptera (Damselflies) belonging to 8 families. The family Libellulidae was the most speciose in Anisoptera with 30 species, followed by Aeshnidae and Gomphidae. Among Zygoptera, Coenagrionidae with 9 species was the most dominant family, followed by Platycnemididae, Calopterygidae, Chlorocyphidae, and Lestidae.

The relative abundance analysis shows that 28 species out of the 47 species of odonates were very common, 10 common, 5 not rare, and 4 rare (Fig. 2). The most abundant species were *Pantala flavescens* (25.57 %), followed by *Brachythemis contaminata*, *Crocothemis servilia*, and *Trithemis pallidinervis* (Fig. 3). Libellulidae was the most abundant family (63.83 %), followed by Coenagrionidae. *Pantala flavescens* (63.83 %) and *Agriocnemis pygmaea* (2.95 %)were the most abundant species in the respective dragonfly and damselfly categories.

The diversity study across the four seasons showed that the maximum species richness and diversity were observed during the northeast monsoon season and the minimum during the summer season. Species richness observed in four different seasons in the paddy fields is summarised in Figure 4. Members of odonate families such as Gomphidae, Libellulidae, Coenagrionidae, and Platycnemididae were observed throughout the seasons (Table 2), whereas Aeshnidae, Calopterigidae, and Chlorocyphidae family members were observed only during the monsoon months. There were seasonal variation in dragonfly and odonate abundance, whereas damselfly abundance was essentially constant throughout the study period.

The present study recorded two endemic species of odonates, one each for the Western Ghats and Peninsular India. The taxon *Agriocnemis keralensis* is endemic to the Western Ghats, and *Libellago indica* is endemic to peninsular India. Out of the 209 species of odonates recorded from the

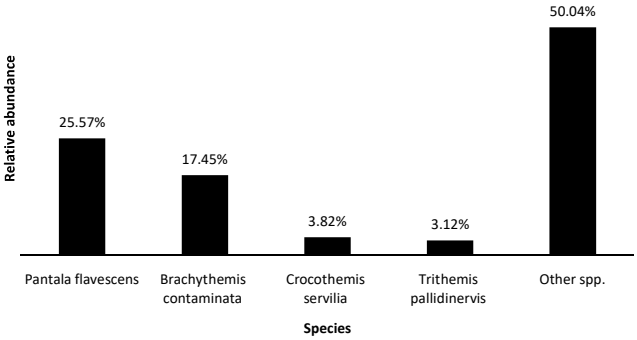

Fig. 2. Relative abundance of the most dominant species in comparison with the rest of the species

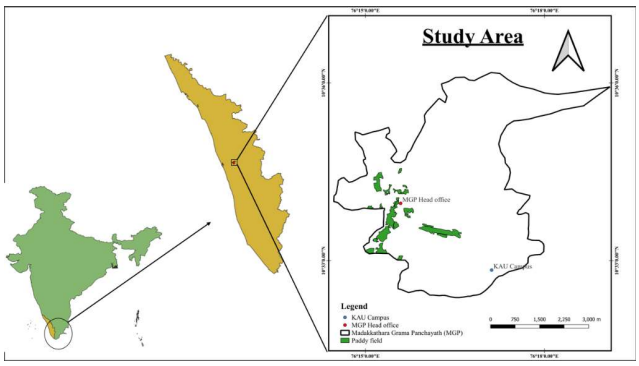

Fig. 1. Study location

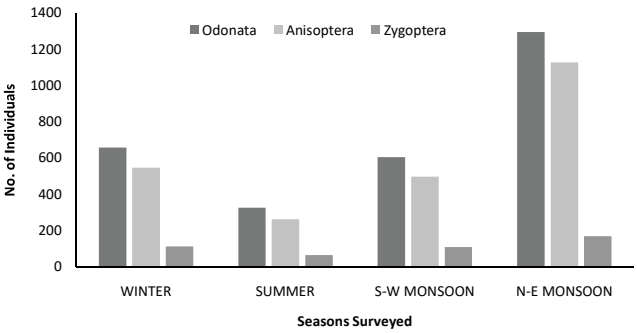

Fig. 3. Species richness observed in four different seasons in the paddy fields of MGP, Thrissur, Kerala

Table 1. Checklist of odonates from the paddy fields of Madakkathara Grama Panchayath, Thrissur, Kerala

Family/Scientific name	IUCN status	Abundance	Seasons recorded in
Anisoptera (Dragonflies)			
Family - Aeshnidae (Darners) – RA: 2.13%			
Gynacantha dravida Lieftinck 1960	DD	RA	M2
Family - Gomphidae (Clubtails) – RA: 2.13%			
Ictinogomphus rapax (Rambur 1842)	LC	VC	W, S, M1, M2
Family - Libellulidae (Skimmers) – RA: 63.83%			
Acisoma panorpoides Rambur 1842	LC	VC	W, S, M1, M2
Aethriamanta brevipennis (Rambur 1842)	LC	VC	W, S, M1, M2
Brachydiplax chalybea Brauer 1868	LC	VC	W, S, M1, M2
B.sobrina (Rambur 1842)	LC	VC	W, S, M1, M2
Brachythemis contaminate (Fabricius 1793)	LC	VC	W, S, M1, M2
Bradinopyga geminate (Rambur 1842)	LC	VC	W, S, M1, M2
Crocothemis servilia (Drury 1770)	LC	VC	W, S, M1, M2
Diplacodes nebulosa (Fabricius 1793)	LC	VC	W, S, M1, M2
D.trivialis (Rambur 1842)	LC	VC	W, S, M1, M2
Hydrobasileus croceus (Brauer 1867)	LC	VC	W, S, M1, M2
Lathrecista asiatica (Fabricius 1798)	LC	NR	S, M1, M2
Neurothemis fulvia (Drury 1773)	LC	CO	W, S, M1, M2
N.intermedia (Rambur 1842)	LC	CO	W, M1, M2
N.tullia (Drury 1773)	LC	VC	W, S, M1, M2
Orthetrum chrysis (Selys 1892)	LC	CO	W, S, M1, M2
O.luzonicum (Brauer1868)	LC	VC	W, S, M1, M2
O.pruinosum (Burmeister 1839)	LC	CO	W, S, M1, M2
O.sabina (Drury1770)	LC	VC	W, S, M1, M2
Pantala flavescens (Fabricius 1798)	LC	VC	W, S, M1, M2
Potamarcha congener (Rambur 1842)	LC	CO	W, M1, M2
Rhodothemis rufa (Rambur 1842)	LC	VC	W, S, M1, M2
Rhyothemis variegata (Linnaeus 1763)	LC	VC	W, S, M1, M2
Tetrathemis platyptera Selys 1878	LC	NR	W, S, M1, M2
Tholymis tillarga (Fabricius 1798)	LC	VC	W, S, M1, M2
Tramea limbate (Rambur 1842)	LC	NR	S, M1, M2
Trithemis aurora (Burmeister 1839)	LC	CO	S, M1, M2
T.festiva (Rambur 1842)	LC	CO	W, M1, M2
T.pallidinervis (Kirby 1889)	LC	VC	W, S, M1, M2
Urothemis signata (Rambur 1842)	LC	VC	W, S, M1, M2
Zyxomma petiolatum Rambur 1842	LC	RA	M2
Zygoptera (Damselflies)			
Family - Coenagrionidae (Narrow-wings) – RA: 19.15%			
Agriocnemis keralensis Peters 1981*	LC	VC	W, S, M1, M2
A.pieris Laidlaw 1919	LC	VC	W, S, M1, M2
A.pygmaea (Rambur 1842)	LC	VC	W, S, M1, M2
Ceriagrion cerinorubellum (Brauer 1865)	LC	VC	W, S, M1, M2
C.coromandelianum (Fabricius 1798)	LC	VC	W, S, M1, M2
Ischnura rubilio Selys 1876	LC	VC	W, S, M1, M2
I.senegalensis (Rambur 1842)	LC	CO	W, S, M1, M2
Pseudagrion microcephalum (Rambur 1842)	LC	VC	W, S, M1, M2
P.rubriceps Selys 1876	LC	VC	W, S, M1, M2
Family - Platycnemididae (White-legs) – RA: 4.26%			
Copera marginipes (Rambur 1842)	LC	NR	M1, M2
Prodasineura verticalis (Selys 1860)	LC	CO	W, S, M1, M2
Family - Lestidae (Spread-wings) – RA: 2.13%			
Lestes praemorsus Hagen in Selys 1862	LC	CO	S, M1, M2
Family - Calopterygidae (Broad-wings) – RA: 4.26%			
Vestalis apicalis Selys 1873	LC	RA	M1
V.gracilis (Rambur 1842)	LC	RA	M1
Family - Chlorocyphidae (Stream jewels) – RA: 2.13%			
Libellago indica (Fraser 1928) **	NE	NR	M1, M2

Image 1: ***Vestalis gracilis***

Image 2: ***Vestalis apicalis***

Image 11: ***Brachidiplax chalybea***

Image 12: ***Hydrobasileus croceus***

Image 3: ***Libellago indica***

Image 4: ***Ischnura senagalensis***

Image 13: ***Brachythemis contaminata***

Image 14: ***Neurothemis tullia***

Image 5: ***Agriocnemis pieris***

Image 6: ***Ischnura rubilio***

Image 15: ***Rhyothemis variegata***

Image 16: ***Diplacodes trivialis***

Image 7: ***Copera marginipes***

Image 8: ***Ceriagrion coromandelianum***

Image 17: ***Trithemis festiva***

Image 18: ***Tholymis tillarga***

Image 9: ***Agriocnemis keralensis***

Image 10: ***Pseudagrion microcephalum***

Image 19***: Orthetrum sabina***

Image 20: ***Lathrecista asiatica***

Image 21: *Trithemis aurora*

Image 22: *Neurothemis fulvia*

Image 23: *Acisoma panorpoides*

Image 24: *Ictinogomphus rapax*

Image 25: *Orthetrum luzonicum*

Image 26: *Crocothemis servilia*

Image 27: *Orthetrum chrysis*

Image 28: *Orthetrum pruinosm*

Image 29: *Pantala flavescens*

Image 30: *Brachydiplax sobrina*

Image 31: *Urothemis signata*

Image 32: *Potamarcha congener*

Western Ghats and 183 species of odonates from Kerala, the present study has accounted for 25.68 % of the odonates in Kerala and 22.49 % of the odonates in the Western Ghats. None of the odonate species from the study area was listed under the Indian Wildlife Protection Act (WPA) of 1972 or the appendices of CITES. Except for *Gynacantha dravida,* which is staged under the 'Data Deficient' category and *Ischnura rubilio* and *Libellago indica,* which are staged under the 'Not Evaluated' category, the rest of the species are listed under the 'Least Concern' category of the IUCN Red List 2022.

One of the most crucial habitats for odonates is paddy fields, where several species primarily reproduce. They hatch when the paddy fields are irrigated, grow swiftly while the water is still in the fields, and emerge before the fields are emptied. This is because their life cycle is synchronised with human activities on the rice crop. The diversity and abundance of these species in paddy fields, however, are less documented in many parts of the world.

A comparable study by Chandran et al (2021) from the Kole wetlands in Central Kerala, located approximately 13 km from the present study location, found a total of 44 species of odonates, including 30 dragonflies and 14 damselflies from eight families. Since the paddy fields serve as ephemeral wetlands, 12 new species that were not listed in Chandran et al (2021) as in the current investigation.

The MGP is also close to the Kerala Agricultural University, Vellanikkara, Thrissur from where 52 species of odonates have been recorded by Adarsh et al (2014), possibly because of the heterogeneity of habitats there. Five new species that had not been previously identified by Adarsh et al (2014), have been reported in this study. The present study has also added three new species, namely *Agriocnemis keralensis*, *Lestes praemorsus*, and *Orthetrum pruinosum*, to the checklist of odonates in Indian paddy fields enlisted in Pavithran et al (2020), thus bringing the total number of odonates recorded from paddy fields to 130.

In the Libellulidae family of Anisoptera and the Coenagrionidae family of Zygoptera, higher species diversity was observed. Ghahari et al (2009) revealed that the Libellulidae and Coenagrionidae families dominated in terms of the number of species in Iranian rice fields. Kumar and Mitra (1998) noted that the family Libellulidae was represented by a high number of species (18 species) out of a total collection of 42 species from Sahstradhara, Dehradun. The current study has shown that the diversity and abundance of odonate fauna show a rise during the Northeast monsoon period. Talmale and Kulkarni (2003) also showed that the odonate population peaks during October and November. This is because paddy fields act as temporary wetlands and remain inundated for more than

Table 2. Family-wise distribution of odonate species in different seasons

Seasons	Aeshnidae	Gomphidae	Libellulidae	Coenagrionidae	Platycnemididae	Lestidae	Calopterygidae	Chlorocyphidae
Winter	0	1	26	9	1	0	0	0
Summer	0	1	27	9	1	1	0	0
Southwest Monsoon	0	1	29	9	2	1	2	1
Northeast Monsoon	1	1	30	9	2	1	0	1

three months, providing ideal breeding conditions for odonates.

CONCLUSION

The study focused on the paddy fields in Madakkathara Grama Panchayath, which are an agriculturally intense area with a good area of land under cultivation. The system of irrigation canals and related tanks, village ponds, and paddy fields in the region provide suitable habitats for odonates. However, changes in land use practices, such as turning paddy fields into nurseries or other crop fields, threaten the local odonate diversity. The study can also be used to show the effects of anthropogenic disturbance on agrobiodiversity, and their significance as indicators of the quality of the biotope. Overall, the study provides important insights into the diversity of odonates in Madakkathara Grama Panchayath and highlights the importance of conserving their habitats to ensure their continued presence in the region.

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Biology and Morphometry of Molsari Leaf Webber, *Nephopteryx eugraphella* Ragonot (Lepidoptera: Pyralidae) on Molsari

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***Abstract*:** Molsari (*Mimusops elengi* Linn.) is a large-sized ornamental tree attacked by many insect-pests with leaf webber- *Nephopteryx eugraphella* Ragonot being the key pest. Biology of *N. eugraphella* was studied on Molsari leaves at PAU, Ludhiana. In all five generations per year were observed and incubation period increased from 3.17 to 4.54 days, while the percent egg hatchability decreased from 90.83 to 72.99 per cent in successive generations. Mean larval period varied from 15.28 days in June to 19.41 days in December. The size of the larvae varied from 1.18- 1.41 × 0.26-0.45 mm in I instar to 19.24-21.88 × 0.99-1.78 mm in full grown larva. Pre-pupal and pupal period ranged between 0.50-2.34 days and 5.89-9.62 days with pupal survival being the highest i.e. 92.79 % in the months of August and September. Adult female and male were 9.50-11.25 mm and 9.00-11.21 mm long and lived for 5.31 to 9.79 and 3.32 to 6.75 days respectively. Gravid female laid 42 to 101.80 eggs and the sex ratio (male: female) ranged between 1:1.13 to 1:1.40. The total life cycle of the insect ranged between 32-45 days. Pest was found to be more active during July, August and September.

Keywords: *Mimusops elengi, Nephopteryx eugraphella,* Biology, Morphometry, Generation

Mimusops elengi Linn. commonly known as Molsari, is a native tree of the western Peninsular region of South India (Halder et al 2018). It is grown as a shade or avenue tree and has many medicinal properties (Ali et al 2008). Leaf webber, termites, grasshoppers, thrips, mealybug, and tent hairy caterpillar are among the insect pests that infest Molsari (Tripathy et al 2020). Foliage feeders (71.42%) are the major insect-pests attacking Molsari followed by bark and sap feeders (28.56%). *Nephopteryx eugraphella* Ragonot-a foliage feeder moth belonging to Pyralidae family is the most common insect pest species (Tripathy et al 2020). Its caterpillar damages the young leaves, apical shoots and flower buds of *M. elengi*. The larvae create a leaf fold within which it feeds, the leaf fold is held together with silken threads and excretal pellets are entrapped in the webs. Young larvae also tend to feed on the internal parts of flowers and flower buds. Thus, the injured flowers and floral buds dry up and do not bear any fruit. It causes immense damage during the rainy season. It was reported that about 90-100% of the plants and 60-80% of foliage were infested by this foliage feeder in Uttar Pradesh thereby giving burning appearance to the trees (Halder et al 2018). *N. eugrephella* has been reported from Bengal, Bihar, Punjab, Tamil Nadu and Madhya Pradesh (Cherian and Ananthanarayanan 1942 and Gupta and Gangrade 1955). Halder et al (2018) published their findings on the biology and bio-intensive management of this pest on Molsari trees in Uttar Pradesh. However, no such detailed and systematic studies have been conducted on biology of *N. eugraphella* on Molsari under Punjab conditions. Keeping in view the damage potential of this pest, the present study on the biology of *N. eugraphella* on Molsari under Punjab conditions has been attempted.

MATERIAL AND METHODS

The study on biology of *N. eugraphella* was carried out during 2021-2022 at Punjab Agricultural University in Ludhiana, Punjab, India. Grown-up larvae of *N. eugraphella* were collected from the Molsari trees and were released on tender Molsari leaves in plastic vials under laboratory conditions. Until pupation, leaves were changed at regular intervals. The pupae were placed in glass jars (13.7 height and 11.4 cm diameter) with a layer of moist sand at the bottom and a sheet of blotting paper on top. In glass jars (15 cm diameter, 19.2 cm height) lined with tissue sheets, five pairs of newly emerged adult male and female were released. Apical shoots of *M. elengi* were provided as oviposition substrate inside the jars. Cotton swabs dipped in a 5 per cent honey solution were given to the moths as food source. The leaves containing freshly deposited eggs were employed for further biological research and five replications were kept. The incubation period and egg hatchability were recorded. Larval duration, larval survival, larval growth index, larval length and larval breadth were observed for larval stage. In case of pupa, duration of pre-pupal period, pre-pupal weight, pre-pupal length, pre-pupal breadth, pupal period, survival, pupation site, pupal weight, pupal length and

pupal breadth were measured. Pre-mating, mating, pre-oviposition, oviposition and post-oviposition periods were also recorded along with longevity of adults, adult length, wing expanse, site of oviposition, mating behaviour, sex ratio and fecundity per female in all the generations throughout the year.

Statistical analysis: The data was subjected to analysis using Statistical Package for the Social Sciences (SPSS) software.

RESULTS AND DISCUSSION

Biological Parameters

Egg stage

Incubation period: Incubation period under laboratory conditions ranged between 2.74 to 4.87 days when moths were reared from G_1 to G_5 (Table 1). Similar to our observations, incubation period of 3-5 days was reported by Shukla and Patel (2011).

Egg hatchability: Hatchability of eggs varied from 72.99 to 90.83 per cent among different generations (Table 1). There was a regular decrease in the hatchability of eggs from G_1 to G_5. Compared to this, 78 to 96 and 80 to 100 per cent viability of eggs was reported by Halder et al (2018) and Shukla and Patel (2011), respectively.

Site and manner of oviposition: Eggs were laid naked on any part of the tender shoots viz., branches, leaf-petioles and leaves. Leaves were the most preferred oviposition site. Even on the leaves, eggs were preferably laid along the midrib on the under surface of the leaf and along leaf-margins. The eggs were mostly laid singly and occasionally in batches of 2-6.

Larval stage

Larval period: The average larval periods in G_1, G_2, G_3, G_4 and G_5 varied from 15.28 to 19.41 days, respectively (Table 1). Halder et al (2018) reported the larval period of 18.38 days. Similarly, larval period of 15.76 days was observed by Shukla and Patel (2011).

Larval survival and growth index: The per cent larval survival varied from 41.44 to 55.47 per cent during different generations while the larval growth index ranged from 2.13 to 3.32 (Table 1). The most favourable period for larval development was from July-September as indicated by better larval survival and higher larval growth index.

Pre-pupal stage

Pre-pupal period: The average pre-pupal periods in G_1, G_2, G_3, G_4 and G_5 ranged from 0.60 to 2.11 days, respectively (Table 1). The pre-pupal period of 2 days was also reported by Patel (1996).

Table 1. Biological parameters of *Nephopteryx eugraphella* Ragonot on molsari

Parameters	Generations									
	I		II		III		IV		V	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Incubation period (Days)	3.17	2.74-3.63	3.48	2.96-3.77	3.87	3.55-4.05	4.15	3.85-4.55	4.54	3.97-4.87
Egg hatchability (%)	90.83		87.64		85.38		78.42		72.99	
Larval period (Days)	15.28	14.70-16.05	15.96	14.72-17.09	16.67	16.16-17.10	18.02	17.66-18.88	19.41	18.91-20.25
Larval survival (%)	48.88		52.56		55.47		44.75		41.44	
Pre-pupal period (Days)	0.60	0.50-0.72	0.75	0.68-0.80	1.07	0.87-1.44	1.86	1.50-2.12	2.11	1.97-2.34
Pupal period (Days)	6.52	5.89-7.09	7.14	5.90-7.82	8.27	7.69-9.13	8.81	7.86-9.36	9.24	8.75-9.62
Pupal survival (%)	85.19		89.38		92.79		80.21		76.25	
Pre-mating period (Days)	1.22	(0.91-1.34)	1.25	(0.97-1.49)	1.31	(0.92-1.66)	1.68	(1.28-2.18)	1.93	(1.49-2.26)
mating period (Days)	0.42	(0.35-0.49)	0.41	(0.37-0.44)	0.47	(0.42-0.56)	0.57	(0.48-0.67)	0.62	(0.58-0.68)
Pre-oviposition period (Days)	1.64	(1.30-1.81)	1.66	(1.41-1.92)	1.78	(1.34-2.16)	2.25	(1.82-2.85)	2.55	(2.08-2.86)
Oviposition period (Days)	2.28	(1.84-2.55)	2.38	(2.01-2.85)	2.80	(2.29-3.32)	3.29	(2.88-3.86)	3.62	(3.44-3.92)
Post-oviposition period (Days)	2.08	(1.33-2.73)	2.24	(1.62-2.85)	2.62	(1.83-3.01)	2.95	(2.63-3.24)	3.21	(2.77-3.45)
Adult longevity (Male)	3.86	(3.32-4.75)	4.28	(3.88-4.76)	4.82	(3.90-5.28)	5.53	(4.89-5.84)	6.33	(5.78-6.75)
Adult longevity (Female)	6.00	(5.69-6.82)	6.28	(5.31-7.07)	7.24	(6.96-7.53)	8.48	(7.62-9.43)	9.38	(9.06-9.79)
Sex ratio (Male : Female)	1:1.18		1:1.30		1:1.13		1:1.40		1:1.25	
Fecundity (No. of eggs/female)	101.80	(94-110)	88.60	(75-105)	70.40	(60-90)	53.60	(42-65)	42.00	(34-52)

Pupal stage

Pupal period: The average pupal periods in G_1 through G_5 was 6.52 to 9.24 days, respectively (Table 1). Similar to present study, the pupal period of 6-9 days was reported by Dongre (2011) and Shukla and Patel (2011).

Pupal survival: Pupal survival varied from 72.99 to 90.83 per cent among different generations (Table 1). Lowest pupal survival was in G_5 (76.25 %) while the highest in G_3 (92.79 %).

Pupation site: Pupation takes place in soil by preparing an earthen cell with an exit hole for the emergence of adult. The newly formed pupae were light green in colour which turned light to reddish brown within 24 hours and become dark brown prior to the emergence of adult. Pupa was broad anteriorly with a tapered posterior end. Compound eyes were prominent. Similar findings have been reported by Shukla and Patel (2011).

Adult stage

Pre-mating and mating period: The average pre-mating period in G_1, G_2, G_3, G_4 and G_5 ranged from 1.22 to 1.93 days, respectively while average mating periods was 0.42, 0.41, 0.47, 0.57 and 0.62 days (Table 1). Pre-mating and mating period of 1.26 and 0.44 days was reported by Shukla and Patel (2011).

Pre-oviposition, oviposition and post-oviposition period: The pre-oviposition, oviposition and post-oviposition periods were ranged from 1.30-2.86, 1.84-3.92 and 1.33-3.45 days, respectively during different generations (Table 1).

Longevity of adults: The longevity of male adults was slightly lesser than females in all the five generations. The average longevity of males in G_1, G_2, G_3, G_4 and G_5 varied between 3.86 to 6.33 days, respectively while female longevity varied between 6.00 to 9.38 days throughout the five generations respectively (Table 1). The average male and female longevity of 4.85 and 8.38 days respectively was reported by Halder et al (2018).

Sex ratio: The sex ratio of male: female in all the five generation was almost similar as it ranged only from 1:1.13 to 1:1.40 (Table 1). This indicates that inbreeding in this insect does not have any adverse effect on the sex ratio.

Fecundity: Fecundity of a moth during different generations (G_1 to G_5) varied from 34-110 eggs under laboratory conditions. However, there was a regular decrease in the fecundity from G_1 to G_5 generations (Table 1). Similar results have also been reported in this pyralid moth by Shukla and Patel (2011). This shows that inbreeding for longer duration causes an adverse effect on the fecundity of this pyralid moth.

Mating behaviour: Mating took place in end to end position and the moths were found mating at least twice during their life span .

Morphometric Parameters

***Larva*:** Length of newly hatched larva ranged between 1.22 to 1.35 mm and breadth ranged between 0.31 to 0.38 mm during different generations (Table 2). Newly hatched larvae were pink which eventually turn yellow within 24 hours. Larval head was pale yellow with one longitudinal median stripe and three purple dorso-lateral stripes on its either side of the body. Prolegs were present on 3rd to 6th and 10th abdominal segments. Prolegs were unjointed, conical and fleshy with crochets that were arranged in a circle. Dorsal surface of body was covered with micro hairs. The full-grown larva ranged from 19.40 to 21.61 mm in length and 1.19 to 1.51 mm in breadth during different generations (Table 2). Head and first thoracic segment were yellowish brown with black lines and spots. Dorsal side of body was pink in colour while ventral side was green. First and third pair of stripes were pink and blended with black spots on each segment while the second pair of stripes were purple in colour. On the second thoracic and eighth abdominal segment a pair of dorso-lateral prominent black spots was present. Prominent longitudinal stripes and hairs were present throughout the body of the larva. These observations are in general agreement with Shukla and Patel (2011).

Pre-pupa: After completion of larval development, final instar larvae stopped feeding and changed its colour from pinkish to greenish. This was the indication of larva undergoing pre-pupal stage. The average weight of pre-pupa in G_1 to G_5 ranged from 47.20 to 55.00 mg, respectively. The length and breadth of pre-pupa varied from 12.41 to 13.44 mm and 2.81 to 3.14 mm, respectively during different generations (Table 2). Patel (1996) also observed pre-pupal length and breadth of 12 to 13 mm and 2.25 to 2.75 mm .

Pupa: The average weight of pupa in G_1 to G_5 ranged between 45.20 to 60.20 mg, respectively. The pupal length varied from 9.72 to 10.88 mm and variation of 2.97 to 3.23 mm was observed in breadth, during different generations (Table 2). Shukla and Patel (2011) also reported pupal length of 9 to 11 mm and breadth of 2.6 to 2.8 mm.

Adult: Adult was greyish in colour with compound black eyes and setaceous antennae. Fore-wings were greyish in colour having four black transverse wavy lines. Hind-wings were membranous and white in colour. Both the wings were fringed at the outer margins. A brownish line was present near the outer margins of both the wings. In females, tip of abdomen was yellow or black with slit like genital aperture, while in males it was pointed and greyish in appearance. The body length varied from 9.00-11.21 mm in male with wing expanse of 18.56-20.60 mm during different generations while it ranged between 9.50-11.25 mm with wing expanse of 19.75-21.03 mm in case of adult females.

Table 2. Morphometrics of *Nephopteryx eugraphella* Ragonot on molsari

Stages of development	Generations									
	I		II		III		IV		V	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Length of I instar larvae (mm)	1.22	1.18-1.28	1.29	1.22-1.38	1.35	1.26-1.42	1.26	1.19-1.40	1.31	1.20-1.41
Length of II instar larvae (mm)	4.18	4.00-4.30	4.41	4.28-4.51	4.65	4.57-4.74	4.52	4.15-4.68	4.48	4.20-4.71
Length of III instar larvae (mm)	13.22	13.10-13.32	13.27	13.19-13.40	13.34	13.16-13.54	13.32	13.14-13.50	13.36	13.22-13.52
Length of IV instar larvae (mm)	19.22	19.00-19.34	19.45	19.24-19.58	19.88	19.80-19.94	19.70	19.54-19.85	19.74	19.50-19.90
Length of full-grown larvae (mm)	19.40	19.24-19.58	20.01	19.60-20.30	21.49	20.72-21.56	20.92	19.90-21.88	21.61	19.87-22.50
Breadth of I instar larvae (mm)	0.31	0.26-0.38	0.32	0.27-0.40	0.38	0.26-0.45	0.35	0.31-0.42	0.33	0.27-0.38
Breadth of II instar larvae (mm)	0.46	0.40-0.55	0.53	0.44-0.60	0.67	0.49-0.78	0.56	0.45-0.66	0.58	0.46-0.67
Breadth of III instar larvae (mm)	0.66	0.52-0.78	0.67	0.55-0.84	0.76	0.57-0.90	0.72	0.54-0.98	0.74	0.58-0.95
Breadth of IV instar larvae (mm)	0.66	0.49-0.85	0.77	0.48-1.22	1.11	0.52-1.48	1.03	0.75-1.39	1.02	0.50-1.28
Breadth of full-grown larvae (mm)	1.19	0.99-1.44	1.21	0.98-1.39	1.48	0.99-1.69	1.44	1.08-1.78	1.51	1.21-1.74
Pre-pupal weight (mg)	47.20	42-52	49.60	45-53	53.80	49-58	49.20	42-59	55.00	47-59
Pre-pupal length (mm)	12.41	12.00-13.00	13.08	12.50-13.54	13.32	12.76-13.70	13.08	12.33-13.68	13.44	13.22-13.70
Pre-pupal breadth (mm)	2.81	2.35-3.37	2.96	2.25-3.54	3.05	2.43-3.55	2.94	2.29-3.60	3.14	2.64-3.58
Pupal weight (mg)	45.20	39-57	55.20	50-65	60.60	55-67	44.40	39-54	60.20	56-64
Pupal length (mm)	9.72	9.17-10.11	10.22	9.25-10.88	10.88	9.86-11.45	10.21	9.40-10.88	10.56	9.67-11.07
Pupal breadth (mm)	3.01	2.70-3.42	3.08	2.88-3.30	2.97	2.68-3.50	3.12	2.71-3.49	3.23	2.94-3.50
Male adult length at resting (mm)	9.62	9.10-10.04	9.89	9.12-10.34	10.44	9.00-11.19	10.07	9.67-10.85	10.32	9.00-11.21
Female adult length at resting (mm)	10.07	9.56-10.70	10.32	9.50-11.25	10.57	9.62-11.20	10.05	9.54-10.78	10.45	9.63-11.19
Male adult length with wing expand (mm)	19.03	18.56-19.78	19.63	19.10-20.09	19.71	18.56-20.60	19.65	18.72-20.30	19.73	18.56-20.55
Female adult length with wing expand (mm)	19.92	19.80-20.03	20.36	19.75-20.77	20.51	19.86-21.00	20.12	19.76-21.02	20.74	20.35-21.03

CONCLUSION

The life cycle of insect was the shortest in the months of rainy season i.e. July and August which coincided with maximum rate of reproduction. The findings of this study will be useful in developing stage targeted pest control strategies that will successfully reduce the pest population by identifying the most vulnerable stage of the pest for effective management.

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Race Composition of Root Knot Nematode (*Meloidogyne*) Species Infecting Cucurbitaceous Crops in Terai region of West Bengal

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***Abstract*:** A survey was undertaken to adequately address the threat of root knot nematode species and races on cucurbitaceous vegetables. In this study, the distribution and identification of root knot nematode species and races collected from different cucurbitaceous vegetable growing areas in Cooch Behar and Jalpaiguri district of Terai region were determined by perineal pattern morphology and North Carolina host differential test during 2020-2022. A total of 31 samples were collected from ten blocks and 74.19% were infested with root knot nematode. Plant root samples were processed in part for identification of species and rest of the sample multiplied on the susceptible host for further detection of races. Response of nematode was measured by counting egg mass and root-galling severity index (1-5 scale). Out of the 31 populations analysed, 69.57% were identified as *Meloidogyne incognita* and rest as *Meloidogyne javanica*. According to the differential host test, population of *M. incognita* existing in Dhupguri, Malbazar, Mathabhanga-II, Haldibari, Dinhata-II, Cooch Behar-II and Tufanganj block of both the district were identified as race 1 (31.25%) and 2 (68.75%). However, populations from Maynaguri, Cooch Behar-I and Mekhliganj block belong to the race 5 and 6 of *M. javanica*. It indicated the presence of *M. incognita* race 2 is the most prevalent race throughout the surveyed area.

***Keywords*:** Cucurbits, Species, Race, *Meloidogyne incognita*, *Meloidogyne javanica*

Cucurbitaceae form an important family of vegetable crops cultivated extensively in the subtropical and tropical countries. The species of this family are distributed all over the world. Cucumbers, gourds, melons, squashes, and pumpkins are among the annual or perennial herbs that belong to this family and are indigenous to temperate and tropical regions. Most of the edible species of guard family are hosts of root knot nematodes. These nematodes infect cucurbit plant roots and complete their life cycle by feeding inside the roots. Plant parasitic nematodes are hidden enemies and continue to tearing farmers for successful and profitable cultivation of horticultural crops. Root-knot nematode (RKN) are the most economically important group of plant parasitic nematodes worldwide attacking nearly almost every crop (Samara 2022). More than 4100 plant-parasitic nematode species have been identified; the most well-known and widely distributed of these is *Meloidogyne* spp. (Singh and Khanna 2016). Root knot nematodes (*Meloidogyne* spp.) are potential threat to the vegetable crops across the world and can result in losses of up to 80% in severely infested regions (Rathod et al 2016). Based on data from the All-India Co-ordinated Research Projects on Nematodes in Agriculture over the years, it has been estimated that phytonematodes cause crop losses of 21.3%, amounting to 102,039.79 million per year. Losses in 19 horticultural crops were estimated to be 50,224.98 million, while losses in 11 field crops were estimated to be 51,814.81 million (Kumar et al 2020). To reduce these losses, is important to manage root knot nematode population in field. For proper management accurate nematode identification is very essential at species and race level and use of resistant cultivars are generally race specific. The different race of a species is difficult to identify because of physical similarities, life phases in different habitats, varied host ranges, poorly defined species borders, intraspecific variability, probable hybrid origin and polyploidy (Blok and Powers, 2009). Therefore, the precise identity (i.e., species and race) of the nematode population being tested must be known in order to develop resistant varieties for the root knot nematode. One of the methods most frequently used to determine the races of root knot nematode species is the differential-host test. The present investigation was carried out to identify the species and races of root knot nematode infesting cucurbitaceous vegetable crop in the districts of Terai region.

MATERIAL AND METHODS

Root-knot nematode (*Meloidogyne* spp.) populations associated with cucurbitaceous crops were collected from

different blocks of Cooch Behar and Jalpaiguri district of West Bengal. A total of 31 root samples were collected, out of which 23 samples from ten blocks (Table 1) were infested with root knot nematode. Plant root samples (galled roots) were processed in part for identification of species based on perineal pattern morphology and rest of the sample multiplied on the susceptible host (tomato cv. Patharkuchi) under net house conditions for further detection of races. This research was conducted in Uttar Banga Krishi Viswavidyalaya during 2020-2022. The differential host test was used to identify the races. For this test plastic pots were filled with sterilised sandy loam soil. The soil sterilized by incorporation of water and formaldehyde solution (37-41%) at 9:1 ratio. Population of each location were tested on NC host differentials (Tomato cv. Rutgers, Pepper cv. California Wonder, Tobacco cv. NC 95, Cotton cv. Deltapine-61 and Peanut cv. Florunner) in different growing season of crops. NC hosts are inoculated with freshly hatched J_2 juveniles of cucurbits collected from different locations. After 75 days of inoculation, host plants uprooted carefully and root system examined for root galling on scale of 1 to 5 based on the number of egg masses produced by each plant, as shown in Table 2. Each plant cultivar was classified as susceptible (+) or resistant (-) depending on multiplication or egg mass production on the root system at the conclusion of the experiment. After that, the data was compared to NC host differential (Taylor and Sasser 1978) and modified scheme (Khan et al 2014) (Table 3).

RESULTS AND DISCUSSION

A total of 31 samples were collected from ten blocks out of which 74.19% were infested with root-knot nematode species based on perineal pattern morphology. After

Table 2. Gall index scale (Gaur 2001)

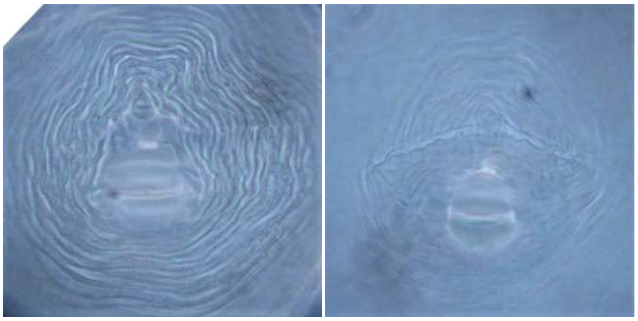
Nematode gall index	Number of egg masses produced by each	Reactions
1	0	Highly resistant
2	1-10	Resistant
3	11-30	Moderately resistant
4	31-100	Susceptible
5	>101	Highly susceptible

Table 1. Root knot nematode infested root samples collected from different location

District	Block	Village/ town	Latitude	Longitude
Cooch Behar	Tufanganj	Turkanikothi	26.362594	89.717768
		Turkanikothi	26.363174	89.728014
		Falimari	26.398017	89.805171
	Mekhliganj	Uchal Pukhari	26.483337	89.022671
		Ranirhat	26.521916	88.965938
		Mekhliganj	26.500122	88.957690
	Haldibari	Budhiapara	26.357436	88.776796
	Mathabhanga-II	Singijani	26.494188	89.152617
		Balasundar	26.521154	89.131519
		Khetifulbari	26.511741	89.090565
	Cooch Behar-I	Charak para	26.203880	89.379533
		Cooch Behar-I	26.270039	89.423983
	Cooch Behar-II	Pundibari	26.397540	89.386389
		Singhimari	26.470146	89.344701
	Dinhata-II	Atialdanga	26.091067	89.571108
		Nazirhat	26.192755	89.563648
Jalpaiguri	Dhupguri	Bamontari	26.670403	88.944926
		Gadong	26.577851	89.042434
		Patkidaha	26.548011	88.986427
	Malbajar	Tesimala	26.857749	88.741053
		Anandapur	26.727363	88.692128
	Maynaguri	Charerbari	26.542397	88.885789
		Bolmari	26.665002	88.767480

comparing the observed data with differential host test reaction chart (Table 3) root-knot nematode (*Meloidogyne*) races infecting cucurbits in Cooch Behar and Jalpaiguri district (Table 4 and 5, respectively). Five host differentials viz., cotton, tobacco, pepper, groundnut and tomato were used for race identification. Out of the infested populations 69.57% were identified as *Meloidogyne incognita* and rest as *Meloidogyne javanica*. Population of *M. incognita* existing in Dhupguri, Malbazar, Mathabhanga-II, Haldibari, Dinhata-II, Cooch Behar-II and Tufanganj block as race-1 (31.25%) and race-2 (68.75%). Populations from Maynaguri, Cooch Behar-I and Mekhliganj block belong to the race-5 and race-6 of *M. javanica.*

The current findings demonstrate the incidence and occurrence of root-knot nematodes (*Meloidogyne* spp.) in the Cooch Behar and Jalpaiguri districts of West Bengal. Most of the cucurbitaceous crops of Cooch Behar and Jalpaiguri districts are affected by *M. incognita* than *M. javanica*. *M. incognita* is identified as the most prevalent and significant species on a locality basis and makes up a major portion of the population of root-knots in these districts. Chandra et al (2010) observed that *Lageneria ciceria*, *Cucumis sativa*, *Momordica charantia*, and *Cucurbita pepo*, the four members of the cucurbitaceae family, were highly or moderately susceptible to *M. incognita*. This report is in accordance with results as most of the localities of cucurbits infected with *M. incognita*. In similar study conducted in Aligarh district of Uttar Pradesh by Ali et al (2021) *Meloidogyne arenaria*, *M. incognita* and *M. javanica* were found in all infested areas associated with eggplant. The dominant species was *M. incognita*, which displayed the highest frequency (86.36%) and second most prevalent species was *M. javanica.* Kalayani et al (2013) reported the concurrent occurrence of *Meloidogyne* spp. in Pothwar region of Pakistan and cucumber had a serious infestation of root-knot nematodes. Chandel et al (2010) in Chhattisgarh, observed highest average population of *Meloidogyne* in bottle gourd followed by bitter gourd and cucumber. On the basis of the differential hosts test, Khan and Murmu (2004) recorded two races of *M. incognita* in crop and weed samples collected from various districts of West Bengal. Populations from Burdwan, Nadia, Birbhum, 24-Pargona (North), Hooghly and Midnapore were identified as *M. incognita* race-2; whereas populations from



Meloidogyne incognita *Meloidogyne javanica*

Table 3. Modified scheme for designation of race/pathotype of *Meloidogyne* based on host differentials

Meloidogyne spp.	Race/ Pathotype	Differential hosts					
		Cotton (Deltapine 61)	Tobacco (NC 95)	Pepper (California Wonder)	Watermelon (Charleston Gray)	Peanut (Florunner)	Tomato (Rutgers)
M. incognita	1	-	-	+	+	-	+
	2	-	+	+	+	-	+
	3	+	-	+	+	-	+
	4	+	+	+	+	-	+
	5	-	-	-		-	+
	6	-	+	-		-	+
M. javanica	1	-	+	-	+	+	+
	2	-	+	-	+	-	+
	3			-		+	
	4			+		+	
	5	-	-	-	-	-	+
	6		+	+	-	-	+
	7	+	+	+		-	+
M. arenaria	1	-	+	+	+	+	+
	2	-	+	-	+	-	+
	3	-	+	+		-	+

Table 4. Identification of root-knot nematode (*Meloidogyne*) races infecting cucurbits in Cooch Behar districts of West Bengal

Location	Host differential										Species	Race
	Cotton		Tobacco		Pepper		Peanut		Tomato			
	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass		
Tufanganj, Turkanikothi	1 (1-1)	0	3.67 (3-4)	24.67 (18-31)	2.33 (2-3)	6.00 (3-9)	1 (1-1)	0	4.00 (4-4)	59.33 (35-88)	*M. incognita*	2
Tufanganj, Turkanikothi	1 (1-1)	0	4.00 (4-4)	28.33 (22-34)	4.00 (4-4)	49.00 (45-54)	1 (1-1)	0	4.00 (4-4)	74.33 (65-85)	*M. incognita*	2
Tufanganj, Falimari	1 (1-1)	0	4.00 (4-4)	50.33 (26-64)	3.67 (3-4)	28.00 (24-32)	1 (1-1)	0	4.00 (4-4)	38.67 (34-47)	*M. incognita*	2
Mekhliganj, Uchal Pukhari	1 (1-1)	0	3.33 (3-4)	19.00 (11-24)	3.67 (3-4)	25.33 (20-32)	1 (1-1)	0	3.00 (3-3)	12.33 (11-14)	*M. javanica*	6
Mekhliganj, Ranirhat	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	3.33 (3-4)	20.67 (15-30)	*M. javanica*	5
Mekhliganj,	1 (1-1)	0	3.00 (3-3)	8.00 (6-10)	2.67 (2-3)	8.67 (5-12)	1 (1-1)	0	3.67 (3-4)	24.67 (20-33)	*M. javanica*	6
Haldibari, Budhiapara	1 (1-1)	0	3.33 (3-4)	17.00 (14-21)	3.00 (3-3)	12.33 (8-15)	1 (1-1)	0	3.00 (3-3)	10.67 (9-12)	*M. incognita*	2
Mathabhanga-II, Singijani	1 (1-1)	0	3.00 (3-3)	10.00 (7-13)	4.00 (4-4)	31.00 (27-35)	1 (1-1)	0	3.33 (3-4)	16.00 (14-19)	*M. incognita*	2
Mathabhanga-II, Balasundar	1 (1-1)	0	1 (1-1)	0	3.33 (3-4)	17.33 (14-23)	1 (1-1)	0	4.67 (4-5)	79.67 (73-84)	*M. incognita*	1
Mathabhanga-II, Khetifulbari	1 (1-1)	0	1 (1-1)	0	3.67 (3-4)	26.67 (21-32)	1 (1-1)	0	4.00 (4-4)	60.00 (53-65)	*M. incognita*	1
Cooch Behar-I, Charak para	1 (1-1)	0	3.00 (3-3)	11.00 (8-15)	4.00 (4-4)	38.67 (35-42)	1 (1-1)	0	5.00 (5-5)	97.67 (86-110)	*M. incognita*	6
Cooch Behar-I,	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	3.67 (3-4)	20.67 (12-27)	*M. javanica*	5
Cooch Behar-II, Pundibari	1 (1-1)	0	3.00 (3-3)	14.67 (12-17)	1 (1-1)	0	1 (1-1)	0	3.33 (3-4)	19.33 (16-22)	*M. javanica*	2
Cooch Behar-II, Singhimari	1 (1-1)	0	2.67 (2-3)	8.33 (5-14)	1 (1-1)	0	1 (1-1)	0	3.67 (3-4)	25.33 (21-28)	*M. incognita*	2
Dinhata-II, Atialdanga	1 (1-1)	0	1 (1-1)	0	3.33 (3-4)	17.33 (15-19)	1 (1-1)	0	3.00 (3-3)	9.33 (6-14)	*M. incognita*	1
Dinhata-II, Nazirhat	1 (1-1)	0	3.00 (3-3)	11.00 (6-15)	2.67 (2-3)	11.33 (4-16)	1 (1-1)	0	4.00 (4-4)	43.00 (42-44)	*M. incognita*	2

*Based on reproduction; Figures in parentheses are the range; **Cotton: cv. Deltapine-61, Tobacco: cv. NC-95, Pepper: California wonder, Peanut: cv. Florunner, Tomato: cv. Rutgers

Table 5. Identification of root-knot nematode (*Meloidogyne*) races infecting cucurbits in Jalpaiguri districts of West Bengal

Location	Host differential										Species	Race
	Cotton		Tobacco		Pepper		Peanut		Tomato			
	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass	Gall Index	Egg mass		
Dhupguri, Bamontari	1 (1-1)	0	1 (1-1)	0	3.00 (3-3)	13.00 (10-16)	1 (1-1)	0	4.00 (4-4)	31.33 (27-35)	*M. incognita*	1
Dhupguri, Gadong	1 (1-1)	0	4.33 (4-5)	102.00 (86-112)	2.67 (2-3)	9.00 (4-12)	1 (1-1)	0	3.67 (3-4)	43.33 (24-55)	*M. incognita*	2
Dhupguri, Patkidaha	1 (1-1)	0	3.00 (3-3)	10.00 (8-12)	2.33 (2-3)	4.33 (3-6)	1 (1-1)	0	3.67 (3-4)	26.00 (20-31)	*M. incognita*	2
Malbajar, Tesimala	1 (1-1)	0	1 (1-1)	0	3.33 (3-4)	15.33 (13-21)	1 (1-1)	0	4.00 (4-4)	41.00 (21-56)	*M. incognita*	1
Malbazar, Anandapur	1 (1-1)	0	4.00 (4-4)	27.67 (21-36)	3.00 (3-3)	7.33 (6-9)	1 (1-1)	0	4.00 (4-4)	61.00 (52-70)	*M. incognita*	2
Maynaguri, Charerbari	1 (1-1)	0	3.00 (3-3)	12.33 (10-14)	3.67 (3-4)	25.67 (18-34)	1 (1-1)	0	2.67 (2-3)	10.00 (4-14)	*M. javanica*	6
Maynaguri, Bolmari	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	1 (1-1)	0	4.00 (4-4)	48.00 (43-52)	*M. javanica*	5

See Table 4 for details

Murshidabad, Malda and Cooch Behar were designated as *M. incognita* race-1. The present study indicates the widespread and diverse nature of the *M. incognita* and *M. javanica* populations that are associated with cucurbitaceous crops in both the districts in Terai region of West Bengal. These findings could be helpful in creating cropping system strategies and in creating species or race-specific resistant varieties for sustainable crop cultivation.

CONCLUSION

M. incognita race-2 is very much prevalent throughout the surveyed area of Cooch Behar and Jalpaiguri district. Their high densities occurrence may pose a serious threat to the crop. Therefore, the immediate attention of growers and researchers is needed to manage the damage caused by root-knot nematodes.

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Perching Behaviour and Seasonal Incidence of Black Drongo, *Dicrurus macrocercus* (Vieillot) on *Apis mellifera* Linnaeus Apiaries under *Terai* Agro-Ecological Region of West Bengal

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***Abstract*:** Black drongo, *Dicrurus macrocercus* is an important insectivorous bird that also feeds on honey bees and is considered as an important natural enemy of Western honey bees (*Apis mellifera* Linn.) causing a significant reduction in the colony strength and honey yield. The present investigation evaluated the perching behaviour and seasonal incidence of *D. macrocercus* in apiary of *A. mellifera* under terai agro-ecological region of West Bengal, India. Black drongo used different trees, shrubs, crops, electric wires, and different other structures for perching with more preference to trees (43.50%) at an average height of 6.93 m. This bird was more active to *A. mellifera* colonies from September–November and was quite successful as a predator (56.27%). Higher activity was during the evening hours i.e. 03:00–04:00 pm (7.04 number of raids) when a greater number of honey bees returned from foraging. The results obtained from the study can be helpful to determine the perching ecology of black drongo and to design appropriate vertebrate predator management protocols against the black drongo that will allow the beekeepers to focus on that particular time period when this pest is more abundant.

***Keywords*:** *Dicrurus macrocercus*, *Apis mellifera*, Perching behaviour, Seasonal incidence

In the present framework of creating entrepreneurship opportunities, beekeeping is one of solitary alternatives. Beekeeping with Western honey bees, *Apis mellifera* Linnaeus is highly promising as they are not ferocious and lead to the production of good quality and quantity of honey. In terai agro-climatic region of West Bengal, *A. mellifera* is found as an important pollinator of different agricultural and horticultural crops (Nath et al 2023) and beekeeping with *A. mellifera* colonies is gaining popularity day by day in this region (Singha et al 2022). However, recent evidences indicate a steady decline in the regional population of both hive and wild honey bees throughout the world (Biesmeijer et al 2006, Potts et al 2010, Saha et al 2023). A number of interconnecting factors including both biotic (insect and non-insect pest, diseases) and abiotic (topographic, environmental conditions etc.) stresses are responsible for the massive decline in honey bee population. Among several biotic stresses passerine insectivorous bird black drongo, *Dicrurus macrocercus* (Vieillot) (Dicruridae: Passeriformes) is found to be a major threat to the bee colonies in different corners of the world (Oldroyd and Nanork 2009, Sharma et al 2018, Parveen et al 2022).

Black drongo is widely distributed throughout the Indian subcontinent (Kaur and Kler 2018). Being a terrestrial bird it perches close to the ground (Okosodo et al 2016) and the height of its perching sites varies greatly (Narayana et al 2014). It perches on electric cables very frequently (Asokan et al 2008). Usually the foraging height of this insectivorous bird depends on various factors such as temperature, season, vegetation structure, abundance and distribution of prey, pray-predator interaction, composition of plant species etc. and collects most of their feed from agriculture land by feeding on bees, wasps, ants, cicadas, grasshoppers, moths, beetles etc. Even they feed on exposed caterpillars in the ploughed field (Asokan et al 2009, Mariappan et al 2013, Narayana et al 2013, Arjun and Paul, 2022). Farmers find it beneficial as it controls some agriculturally important insect pests to some extent. But it is a nuisance to beekeepers as they prey upon the honey bees and affect their colony strength (Fig. 4). Keeping in view the importance of foraging ecology of black drongo in determination of its habitat utilization and role on beekeeping under terai region of West Bengal, the present study has been designed to determine the perching behaviour and seasonal incidence of black drongo on *Apis mellifera* colonies in the region under consideration.

MATERIAL AND METHODS

Study area: The study was conducted at the apiary unit of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari,

Cooch Behar, West Bengal, India during 2019. The apiary unit is located at 26°19' N latitude and 89°23' E longitude and at an altitude of 43 meter above the mean sea level (MSL). To carry out the investigation a total of ten *A. mellifera* colonies having similar strength has been placed in the apiary unit. No vertebrate pest management strategies were undertaken in the apiary unit and the colonies were only fed with sugar-syrup solution during the dearth period to maintain the colony strength. For monitoring of birds a 360^0 viewing CCTV Camera was installed in the apiary unit and the recorded movie was considered for analysing the activity of birds.

Climatic condition of study area: The terai agro-ecological region of West Bengal is characterized by typical per humid climatic conditions. This region has an annual average rainfall of more than 3000mm and the relative humidity is about 65-90%. About 80% of the total rainfall of this region is caused by the South-West monsoon during the rainy season i.e. June-September. However, the rainfall pattern is erratic and not distributed uniformly throughout the year. Average maximum and minimum temperatures are 24°C and 33.2°C. The whole area is characterized by humid and warm weather except having a short spell of cold during December-February months.

Assessment of perching behaviour of black drongo: As black drongo utilized various plant species for perching, so different trees, shrubs and crops present in and near the apiary unit have been identified. The recorded movie has been analyzed and direct observation also taken to determine the utilization of various perching sites by black drongo. For determination of perching height data was recorded 15 times per month for an observation period of 30 minutes during 3:30 to 4:30 pm when their activity was high (Kaur and Kler 2018). The perching height was measured as per stick method recommended by Hairiah et al (2001) without disturbing the birds. Monthly 50 birds have been observed to evaluate the percentage utilization of various perching sites. Photographs on the activity of black drongo has been captured using Nikon D5600 and Nikon D5300 cameras.

Assessment of seasonal incidence of black drongo: For estimation of seasonal incidence of black drongo, their foraging activity on *A. mellifera* has been carefully monitored near the apiary unit. Data was recorded during the active foraging period at a time gap of one hour, viz. 09:00-10:00, 11:00-12:00, 13:00-14:00 and 15:00-16:00 by analysing/viewing the recorded movie and also by direct observation. Data was recorded with regard to continuous stay by the birds in the apiary site during the study time, number of successful attempts to catch the bees, number of unsuccessful attempts to catch the bees, total number of attempts, number of individual birds in raid, and number of raids by a bird.

RESULTS AND DISCUSSION

Perching behaviour of black drongo: Black drongo was found to utilize different trees, shrubs, crops and electric power lines for perching (Fig. 1). Some other structures like instructional boards, bamboo pegs, rice stubbles, fencing were also utilized by them for perching. Different plant species were found to be utilized by black drongo surrounding the apiary (Table 1). Among different tree species *Acacia auriculiformis* and *Neolamarckia cadamba* were most preferred perching sites. Among different crops *Zea mays* and *Sesbania bispinosa* were utilized for perching. *Bougainvillea glabra* was an important shrub plant used for perching by black drongo. The highest perching height was noted in electric cables (7.32m) followed by trees (6.93 m) (Table 2). The black drongo preferred to perch on comparatively low height during March-April on trees which also coincided with their breeding period. In rest of the period the perching height was little higher on trees. But no such height preference was noted on electric cables, shrubs and other structures and remains more or less similar round the year. Black drongo preferred to perch on trees compared to other perching sites with a percentage utilization rate of 43.50% (Fig. 2). This may be due to the presence of more trees near the apiary and such high elevation also allowed them a good searching view. The perching site utilization

Table 1. Utilization status of different plant species by black drongo surrounding the apiary unit during 2019-20

Tree	Utilization for perching (+/–)*	Tree	Utilization for perching (+/–)*	Shrub	Utilization for perching (+/–)*	Crop	Utilization for perching (+/–)*
Acacia auriculiformis	+	*Delonix regia*	+	*Murraya paniculata*	+	*Zea mays*	+
Neolamarckia cadamba	+	*Psidium guajava*	–	*Bougainvillea glabra*	+	*Oryza sativa*	–
Azadirachta indica	+	*Murraya koenigii*	–	*Hibiscus rosa-sinensis*	–	*Triticum aestivum*	–
Caesalpinia pulcherrima	+	*Litchi chinensis*	–	*Lagerstroemia indica*	+	*Brassica* sp.	–
Callistemon sp.	+	*Bauhinia acuminata*	–	*Jasminum multiflorum*	–	*Sesbania bispinosa*	+

*'+' indicates utilized for perching and '–' indicates not utilized for perching

pattern was trees>other structures>electric cable>ground> crops.

Kaur and Kler (2018) also observed that trees were most utilized perching sites by the black drongo with average perching height of 12.9 3 m to 13.28 m on electric cables and 13.43 m to 15.93 m on trees. Arjun and Paul (2022) also recorded the maximum perching height of 12m and minimum of 10m. But in the current investigation the recorded perching height was less, that may be due to the variation in topography, environment and vegetation structure. Another reason may be the trees that were utilized by the black drongo in the study area were of relatively low height. Near the apiary main food was the foraging bees and as the bees forage on a low elevation from the ground that also may be responsible for the low perching height of black drongo.

Seasonal incidence of black drongo: The maximum activity of the *D. macrocercus* on the *A. mellifera* colonies was during September-November with peak incidence in October (31 individual birds making a total of 97attempts on honey bees) (Table 3, Fig. 3). After that there was a steady

Table 2. Average perching height in different perching sites of black drongonear the apiary unit during 2019-20

Months	Perching height in different perching sites (Mean±S.E.) (m)			
	Electric cables	Trees	Shrubs	Other structures
September	7.33±0.12	7.03±0.19	1.43±0.07	0.95±0.18
October	7.34±0.09	6.95±0.18	1.35±0.04	1.07±0.16
November	7.41±0.11	7.03±0.26	1.33±0.06	0.92±0.12
December	7.36±0.10	6.99±0.14	1.37±0.09	1.09±0.15
January	7.45±0.10	7.09±0.14	1.34±0.07	0.91±0.13
February	7.37±0.10	7.11±0.13	1.30±0.07	1.01±0.13
March	7.33±0.09	6.90±0.11	1.19±0.06	0.97±0.12
April	7.45±0.09	6.92±0.12	1.28±0.05	1.05±0.14
May	7.11±0.10	6.78±0.14	1.20±0.05	0.91±0.10
June	7.30±0.10	6.83±0.10	1.22±0.05	0.99±0.12
July	7.18±0.08	6.53±0.16	1.28±0.07	0.95±0.12
August	7.17±0.07	6.99±0.07	1.33±0.06	0.92±0.13
Mean±S.E.	7.32±0.03	6.93±0.05	1.30±0.03	0.98±0.02

Table 3. Seasonal incidence of black drongo, *Dicrurus macrocercus* during 2019-20 (Mean±S.E.)

Months	Number of individual birds encountered in attack	Number of attacks observed	Raid/ individual bird	Raids by the birds in a day during study time	Number of successful attacks observed	Number of successful raids/day	% of successful raids	Number of unsuccessful attacks observed	Number of unsuccessful raids/day	% of unsuccessful raids
September	25	73	2.92	18.25±1.70	42	10.50±0.96	57.56±0.42	31	7.75±0.75	42.44±0.42
October	31	97	3.14	24.25±2.63	51	12.75±1.75	52.21±1.72	46	11.5±0.96	47.79±1.72
November	29	81	2.79	20.25±0.75	44	11.00±0.58	54.24±1.07	37	9.25±0.25	45.76±1.07
December	18	50	2.78	12.50±3.38	27	6.75±1.89	53.22±1.13	23	5.75±1.49	46.78±1.13
January	16	30	1.88	7.50±1.85	18	4.50±1.04	60.97±6.57	12	3.00±0.91	39.03±6.57
February	23	59	2.57	14.75±1.31	34	8.50±0.96	58.00±5.01	25	6.25±1.03	42.00±5.01
March	26	60	2.31	15.00±2.38	34	8.50±1.50	56.39±2.37	26	6.50±0.96	43.61±2.37
April	22	56	2.55	14.00±1.47	31	7.75±0.85	55.28±0.72	25	6.25±0.63	44.73±0.72
May	25	64	2.56	16.00±2.45	35	8.75±1.55	54.36±2.52	29	7.25±1.03	45.64±2.52
June	20	46	2.30	11.50±1.04	27	6.75±0.48	59.17±2.62	19	4.75±0.63	40.83±2.62
July	22	61	2.77	15.25±2.10	33	8.25±1.25	54.17±2.92	28	7.00±1.08	45.83±2.92
August	22	65	2.95	16.25±1.11	39	9.75±1.03	59.66±3.60	26	6.50±0.50	40.34±3.60
Total	279	742	---	---	415	---	---	327	---	---
Mean±S.E.	---	---	2.63±0.10	---	---	---	56.27±0.81	---	---	43.73±0.81

decline in their incidence up to January. Lowest incidence was in January when the ambient temperature was low enough. Though their incidence never came down to zero at any point of the year. From February with increasing temperature their incidence also started increasing with a more or less similar population during the hotter months of the year. During the entire study period 279 birds were encountered making 742 attempts against the Western

Fig. 1. Different perching sites utilized by black drongo near the apiary unit during 2019-20

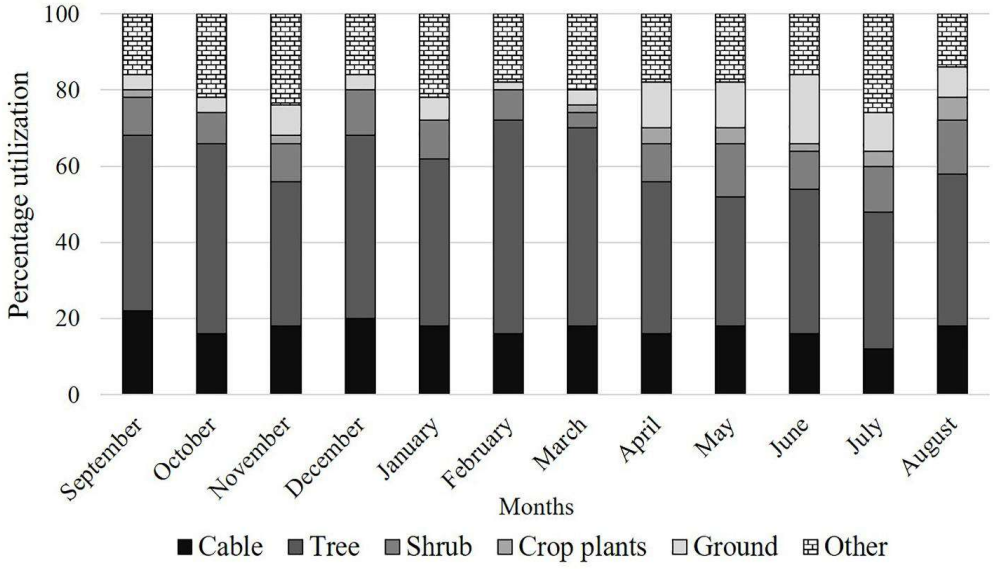

Fig. 2. Percentage utilization of various perching sites by black drongo in the apiary during 2019-20

Table 4. Time variation in the incidence of black drongo, *Dicrurus macrocercus* during 2019-20 (Mean± S.E.)

Months	Time duration	Duration of staying in the apiary during one hour interval	No. of birds involved in attack	No. of raids carried out by the birds	No. of raids/min (during staying in the apiary)
September	09:00-10:00	9.25±3.25	1.00±0.41	2.00±1.22	0.22±0.05
	11:00-12:00	17.25±1.11	1.00±0.00	2.25±0.85	0.14±0.08
	01:00-02:00	23.00±3.14	1.25±0.25	4.00±1.08	0.21±0.04
	03:00-04:00	45.75±2.78	3.00±0.41	10.00±1.41	0.21±0.03
October	09:00-10:00	11.25±1.49	1.50±0.29	3.50±1.26	0.35±0.12
	11:00-12:00	15.75±5.72	0.75±0.25	2.00±0.71	0.13±0.01
	01:00-02:00	33.25±3.12	2.25±0.25	8.00±2.04	0.24±0.05
	03:00-04:00	56.25±3.75	3.25±0.25	10.75±0.85	0.19±0.02
November	09:00-10:00	9.50±2.10	0.50±0.25	1.25±0.75	0.10±0.06
	11:00-12:00	14.00±1.96	0.75±0.25	3.00±1.08	0.21±0.07
	01:00-02:00	24.75±2.06	1.25±0.29	4.75±0.63	0.20±0.04
	03:00-04:00	41.75±6.30	2.00±0.25	11.25±0.63	0.29±0.04
December	09:00-10:00	7.75±5.01	0.50±0.29	1.25±0.75	0.17±0.02
	11:00-12:00	7.75±3.30	0.75±0.25	1.50±0.65	0.19±0.01
	01:00-02:00	17.50±3.23	1.25±0.25	2.75±0.85	0.15±0.02
	03:00-04:00	26.25±4.27	1.50±0.41	7.00±1.35	0.26±0.03
January	09:00-10:00	6.75±4.31	0.75±0.29	0.50±0.50	0.06±0.06
	11:00-12:00	8.75±3.15	1.00±0.25	0.75±0.48	0.08±0.04
	01:00-02:00	16.25±1.75	1.50±0.25	2.75±0.75	0.16±0.03
	03:00-04:00	23.75±2.53	2.50±0.29	3.50±0.65	0.15±0.03
February	09:00-10:00	8.75±3.15	1.00±0.25	1.00±0.58	0.11±0.06
	11:00-12:00	18.25±3.07	1.50±0.00	2.00±0.71	0.13±0.05
	01:00-02:00	24.75±2.06	1.75±0.29	4.25±0.75	0.17±0.03
	03:00-04:00	30.50±0.96	2.25±0.29	7.50±1.19	0.25±0.04
March	09:00-10:00	10.75±0.75	1.00±0.00	1.75±0.63	0.17±0.06
	11:00-12:00	18.00±2.86	1.00±0.29	3.25±1.38	0.26±0.07
	01:00-02:00	23.00±2.38	1.50±0.48	4.25±1.44	0.22±0.08
	03:00-04:00	32.00±2.86	2.00±0.25	5.75±0.48	0.20±0.02
April	09:00-10:00	9.50±1.26	1.00±1.26	2.00±0.41	0.25±0.09
	11:00-12:00	11.75±1.18	1.00±0.00	2.25±0.85	0.21±0.09
	01:00-02:00	24.50±1.32	1.50±0.29	3.75±0.75	0.16±0.03
	03:00-04:00	32.50±3.23	2.00±0.41	6.00±1.08	0.19±0.04
May	09:00-10:00	7.50±3.23	0.75±3.23	1.67±0.76	0.13±0.07
	11:00-12:00	13.50±0.87	1.25±0.48	2.00±1.22	0.13±0.08
	01:00-02:00	27.75±3.47	2.00±0.41	5.25±1.03	0.20±0.04
	03:00-04:00	30.25±4.66	2.25±0.25	7.50±1.55	0.29±0.11
June	09:00-10:00	6.25±2.53	0.75±2.53	0.67±0.58	0.06±0.06
	11:00-12:00	14.00±2.94	1.00±0.00	2.50±0.29	0.21±0.06
	01:00-02:00	21.75±2.39	1.75±0.48	4.25±1.11	0.21±0.07
	03:00-04:00	34.75±2.43	1.50±0.29	4.25±0.75	0.13±0.03
July	09:00-10:00	9.25±1.49	1.00±1.49	2.00±0.41	0.32±0.12
	11:00-12:00	15.75±1.65	1.25±0.25	3.50±0.65	0.28±0.07
	01:00-02:00	17.50±3.23	1.75±0.25	5.25±0.85	0.31±0.02
	03:00-04:00	38.00±3.39	1.50±0.29	4.50±0.65	0.15±0.07
August	09:00-10:00	10.50±2.10	0.75±2.10	2.00±0.71	0.25±0.15
	11:00-12:00	12.50±1.04	1.25±0.25	3.75±1.11	0.33±0.13
	01:00-02:00	20.75±2.17	1.50±0.29	4.00±0.71	0.19±0.02
	03:00-04:00	33.50±2.36	2.00±0.41	6.50±0.87	0.20±0.04

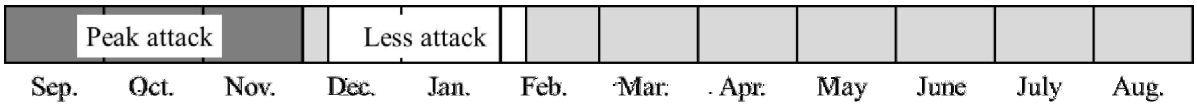

Fig. 3. Seasonal occurrence of black drongo at different months during 2019-20

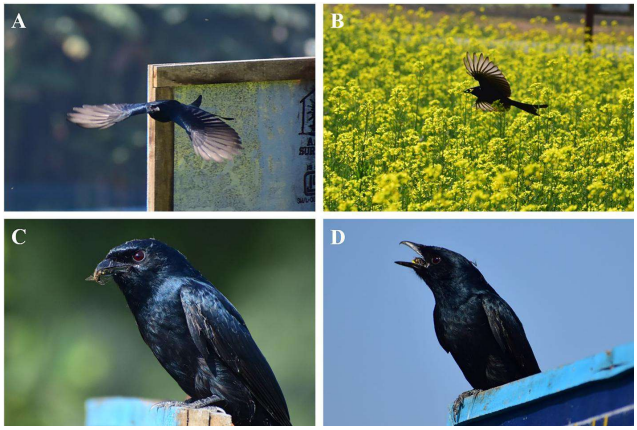

Fig. 4. Act of predation of black drongo on *Apis mellifera* near the apiary. (A) Looking for the prey, (B) Locating and capturing the prey, (C) Returning to the perching site with the prey and (D) Devouring the prey

honey bees. They were found quite successful as an aerial predator of honey bees with a success ratio of 56.27%. The average number of raids per bird during the study period was recorded 2.63 raids/bird. They were least active at early morning hours, viz. 09:00-10:00 am (1.63 number of raids) and thereafter activity increased gradually. Even black drongo birds were found to catch the returning bees from close to the hives and were most active during evening hours, viz. 03:00-04:00 pm (7.04 number of raids). They also spent maximum time in the apiary during this time gap (Table 4). Higher activity during this time interval may be due to a greater number of forager bees returned to the hive at this point of time. Their activity was very less during the initial hours of the day that might be due to the presence of cool weather and less activity of honey bees during the early morning and activity kept increasing as time passed. Sharma et al (2018) also recorded that *Dicrurus* sp. attacking honey bees during April to October months in Kullu valley. The slight difference in the result obtained in the current investigation with the above mentioned work is due to the variation in prevailing environmental condition, topography and position of colony with the food sources.

CONCLUSIONS

Black drongo utilized different sites like trees, shrubs, electric cables, crops, bamboo pegs, stubbles, instructional boards, sheds etc. for perching with more preference to the trees. However their perching height differs significantly that may be based on several biotic and abiotic factors. Farmers consider this bird as an important natural enemy to different economically important insect pests. But beekeepers of this region consider it as a threat to their bee colonies as it has a negative impact on the colony strength. Incidence of black drongo is high during September to November. Though this bird is present throughout the year. This the optimum time when different integrated management strategies need to be implemented to protect the colonies from severe loss. This includes active monitoring of bee colonies so that higher loss caused by this bird can be addressed as soon as possible and based on that proper vertebrate management strategies can be incorporated. Though beekeeping is not that much popularized in the terai region as compared to the other parts of West Bengal, but as the rural peoples get aware about the importance of beekeeping in the socio economic development, its popularity also starts increasing day by day. But proper care of the colonies need to be taken to protect them from different biotic stresses otherwise it will cause a great loss to the beekeepers creating a threat to the country's economy.

AUTHORS' CONTRIBUTION

Designed the research work: Sibananda Singha, Nripendra Laskar. Performed the field work: Sibananda Singha, Riju Nath. Statistical analysis: Samrat Saha, Adrish Dey. Wrote the paper: Samrat Saha, Pushpa Kalla, Nripendra Laskar. Photography: Samrat Saha, Riju Nath, Adrish Dey.

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Influence of Transgenic Cotton Cultivars on Growth and Development of *Pectinophora gossypiella* (Saunders)

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***Abstract*:** The reinvasion of pink bollworm, *Pectinophora gossypiella* has imposed threats in cultivation of Bt cotton in India. The information on life cycle of *P. gossypiella* on various transgenic cotton cultivars grown widely under Punjab conditions is lacking. Therefore, present research on four BG II cotton cultivars namely, Ankur Jassi, MRC 9024, RCH 776, SP 7172; two Bt cotton varieties namely, PAU Bt 2, PAU Bt 3 and non-Bt cotton variety, F 2228 was carried out. The mean larval span was significantly lower on BG II cotton cultivars and higher on non-Bt cotton cultivar. Larval and pupal weight, larval and pupal survival was higher on non-Bt cotton in comparison to BG II cotton cultivars. Except for fecundity, BG II cotton has significant detrimental effect on other vital parameters of *P. gossypiella*. Overall, it can be concluded that BG II cotton cultivars namely, Ankur Jassi and MRC 9024 have most detrimental effect on various biological parameters of *P. gossypiella* and these cultivars can be recommended for cultivation under Punjab condition in integration with other management tactics.

***Keywords*:** *Pectinophora gossypiella,* BG II cotton, Non-Bt cotton, Life cycle

Cotton (*Gossypium* spp.) is an important cash crop in India as well as in Punjab, and plays an important role in social and economic well being of people. India is the largest producer of cotton in the world having area of 130.07 lakh ha with a production of 353.84 lakh bales and productivity of 462.46 kg lint per ha during 2020-21 (Indiastat 2021). Among the various constraints, insect pests are posing major hurdle in the success of cotton cultivation. Various bollworms, including the pink bollworm, *Pectinophora gossypiella* (Saunders), cause serious losses leading to reduction in cotton yield. Bt cotton cultivars having *Cry* genes were introduced in India in 2002 (*Cry1Ac*) and 2006 (*Cry1Ac+ Cry2Ab*), for control of major bollworms of cotton particularly, American, spotted and pink bollworm. Bt cotton was working well against all the bollworms until 2009, when there was infestation of *P. gossypiella* in Gujarat reported to be feeding on single gene Bt cotton. Later, in 2015, the incidence of pink bollworm was again recorded on BG II cotton cultivars in Gujarat. *P. gossypiella* emerged again as a menace on Bollgard cultivars in central and south Indian cotton growing states like Andhra Pradesh, Gujarat, Maharashtra, Karnataka and Telangana after 2015 (Naik et al 2018). In 2021, outbreak of PBW was observed in northern states of Haryana and Punjab. As India is largest producer of cotton worldwide, the reinvasion of pink bollworm has imposed threats in cultivation of Bt cotton.

The pink bollworm, *P. gossypiella* is one of the most destructive bollworms of cotton around the world (Fand et al 2019). WW Saunders gave its first description in 1843 as *Depressaria gossypiella* in 1842 from Gujarat. *P. gossypiella* is considered as 'difficult to control bollworm' because of cryptic habitat of feeding of its larvae inside flowers and bolls. In Punjab, only scanty information is available on development of *P. gossypiella* on various Bt cotton cultivars. Therefore, present research was carried on BG II cotton, Bt cotton and non-Bt cultivars to study the various biological parameters of PBW for understanding its biology for its sustainable management.

MATERIAL AND METHODS

Test cultivars: Four BG II cotton cultivars namely, Ankur Jassi, MRC 9024, RCH 776, SP 7172; Bt cotton varieties namely, PAU Bt 2, PAU Bt 3 and non-Bt cotton variety, F 2228 were selected because of their larger area of cultivation under Punjab conditions. These were sown at Entomological Research Farm by following proper agronomic practices.

Rearing culture of *P. gosspiella:* Larval of *P. gossypiella* were collected from cotton fields of Bathinda district of Punjab and reared on fresh flowers of non-Bt cotton variety, F 2228 until their pupation in IPM Laboratory, PAU Ludhiana. The pupae were sexed based on size and morphological characteristics (Dharajothi et al 2016). The newly emerged adults obtained from the culture were released @ 10 pairs in one plastic jar (45 × 20 cm size) for egg laying as per procedure followed by Fand et al (2019). Two cotton swabs each of 10 per cent honey solution and water were hung in oviposition jars as adult food source. The jar was covered with black paper from outside to simulate dark conditions

ideal for egg laying. Adult moths were transferred to new jars having fresh twigs and food source throughout the oviposition period of female at an interval of two days. For carrying out biological studies of *P. gossypiella*, newly hatched first instar larvae were collected from these twigs and released on flowers of test cotton cultivars.

Life cycle of *P. gossypiella* on test cultivars: The study on life stages of *P. gossypiella* on four Bollgard II cotton hybrids, two Bt cotton varieties and non-Bt cotton cultivars was carried out during August, 2021. The stage of test cultivars was of 90-120 days after sowing (31st to 34th SMW). For recording larval span, thirty first instar larvae were taken in three replications for each test cultivar. Fresh flowers of each cultivar were kept in three plastic jars (45 × 20 cm size) for first and second instar larvae. Third and fourth instar larvae were reared on the bolls of various test cultivars. The food was changed after two days (fresh flowers and bolls) depending upon the stage of the larvae till their pupation. The adults were reared as per procedure followed earlier. To record female pre-oviposition, oviposition and post-oviposition period and fecundity, three pairs of freshly emerged adults were released into oviposition jar. Male longevity was also recorded. Cotton bolls in each oviposition jars were replaced after every two days interval till the death of the female. The experiment was conducted under 30.95±0.44°C temperature and 72.63±3 per cent relative humidity in laboratory conditions. The observations on egg period, larval period, larval weight, pupal period, pupal weight, total developmental period, adult longevity, pre-oviposition, oviposition and post oviposition period, fecundity, larval and pupal mortality were recorded on each test plant. Observations were taken twice a day to keep record of various biological parameters of *P. gossypiella* on above-mentioned cultivars. Larval weight was recorded for fully matured fourth instar larva. Weight of pupae (male and female) was recorded 48 hours after pupation. By dividing the number of dead individuals by the total number of individuals used in the study, percent mortality was worked out for each cultivar.

Statistical analysis : One-way analysis of variance was used for analyzing various developmental parameters (Statistix 10 software) and the significance of various treatments was evaluated using Tukey's test.

RESULTS AND DISCUSSION

The larval period was shorter on BG II cotton cultivars, Ankur Jassi (15.08 days) being at par with SP 7172, MRC 9024, PAU Bt 3 and PAU Bt 2. However, it was significantly longer on F 2228 (19.93 days) being at par with RCH 776. Zinzuvadiya et al (2017) observed total larval span in range of 17.50 and 18.15 days for larvae separated as male and female, respectively. The pupal duration was in range of 7.94 (SP 7172) to 9.48 days (PAU Bt 2) and statistically no significant differences were observed among various cultivars. Total development period was significantly lower on Ankur Jassi (26.65 days) being at par with SP 7172 and MRC 9024. Our findings on pupal period are in agreement with the findings of Adkisson et al (1960) and Fand et al (2019). The longer developmental period was observed on non-Bt cotton cultivar, F 2228 (33.37 days) being at par with PAU Bt 2 and RCH 776 followed by PAU Bt 3.

No significant difference in pre-oviposition, oviposition and post-oviposition period and mean female longevity of *P. gossypiella* were recorded among various cotton cultivars (Table 1). Zinzuvadiya et al (2017) also reported the pre-oviposition, oviposition and post-oviposition period of 2.91, 8.00 and 4.30 days, respectively. Male longevity significantly ranged from 8.44 (MRC 9024) to 10.67 (PAU Bt 3) days, which was significantly longer on PAU Bt and non-Bt cotton varieties as compared to BG II cotton cultivars. Fand et al (2019) reported similar results.

Egg period was in range of 3.38 (Ankur Jassi) to 4.54

Table 1. Effect of cotton cultivars on various life stages of *Pectionophora gossypiella*

Cultivars	Duration of various stages (days)								
	Egg	Larval	Pupal	Total development	Pre-oviposition	Oviposition	Post-oviposition	Adult female	Adult male
MRC 9024	3.89^{bc}	15.73^{b}	9.08^{a}	28.70^{cde}	2.17^{a}	8.67^{a}	1.20^{a}	12.04^{a}	8.44^{ab}
SP 7172	4.21^{ab}	15.52^{b}	7.94^{a}	27.67^{de}	2.76^{a}	9.45^{a}	1.25^{a}	13.47^{a}	9.68^{abcd}
Ankur Jassi	3.38^{c}	15.08^{b}	8.19^{a}	26.65^{e}	2.60^{a}	9.21^{a}	1.44^{a}	13.26^{a}	8.55^{ab}
RCH 776	4.00^{abc}	18.56^{a}	9.43^{a}	31.99^{ab}	2.74^{a}	9.66^{a}	1.04^{a}	13.44^{a}	8.87^{ab}
PAU Bt 2	4.54^{a}	16.56^{b}	9.48^{a}	30.58^{abc}	2.61^{a}	9.18^{a}	1.35^{a}	13.14^{a}	10.43^{cd}
PAU Bt 3	4.40^{ab}	16.02^{b}	9.36^{a}	29.78^{bcd}	2.48^{a}	10.39^{a}	1.19^{a}	14.06^{a}	10.67^{d}
F 2228	4.35^{ab}	19.93^{a}	9.00^{a}	33.37^{a}	2.41^{a}	9.64^{a}	0.94^{a}	12.98^{a}	9.87^{bcd}

Values within each test followed by a different letter are significantly different at $p < .05$ by Tukey Test (one-way ANOVA); Mean of 3 replications

Table 2. Weight of larvae and pupae of *Pectionophora gossypiella* on various cotton cultivars

Cultivars	Fourth larval instar	Female pupa	Male pupa	Fecundity/ female
	Weight (mg)			
MRC 9024	15.89^{ab}	21.72^{a}	9.78^{b}	29.00^{b}
SP 7172	17.46^{ab}	16.75^{a}	11.28^{ab}	36.00^{b}
Ankur Jassi	12.54^{b}	18.90^{a}	9.83^{b}	51.00^{a}
RCH 776	19.69^{a}	18.80^{a}	14.13^{ab}	50.00^{a}
PAU Bt 2	21.21^{a}	18.29^{a}	15.97^{a}	32.00^{b}
PAU Bt 3	16.84^{ab}	17.39^{a}	11.66^{ab}	16.00^{c}
F 2228	22.50^{a}	20.10^{a}	16.63^{a}	50.00^{a}

Values within each test followed by a different letter are significantly different at $p < .05$ by Tukey Test (one-way ANOVA)

Table 3. Mortality of immature stages of *Pectionophora gossypiella* on various cotton cultivars

Cultivars	Mortality of immature stages (%)		
	Ist instar larvae	IInd to IVth instar larvae	Pupa
MRC 9024	23.33^{a}	17.26^{ab}	20.64^{a}
SP 7172	20.00^{ab}	25.27^{a}	16.99^{ab}
Ankur Jassi	23.33^{a}	12.17^{b}	14.29^{ab}
RCH 776	13.33^{bc}	19.45^{ab}	13.10^{ab}
PAU Bt 2	11.67^{c}	20.51^{ab}	20.38^{a}
PAU Bt 3	22.22^{a}	24.08^{a}	12.50^{ab}
F 2228	10.00^{c}	3.73^{c}	7.87^{b}

Values within each test followed by a different letter are significantly different at $p < .05$ by Tukey Test (one-way ANOVA)

days (PAU Bt 2) being lower on BG II cotton and higher on non-Bt and Bt cotton cultivars. The larval weight was higher on non-Bt cotton in comparison to BG II cotton hybrids. It was significantly lower on Ankur Jassi (12.54 mg) being at par with MRC 9024, PAU Bt 3 and SP 7172. However, it was significantly higher on F 2228 (22.50 mg) being statistically at par with PAU Bt 2 and RCH 776 (Table 2). Rajput et al (2018) also observed larval weight as 13.84 and 20.24 mg on Bt and non-Bt cotton, respectively. No significant differences were observed in female pupal weight on different cultivars. However, it was lowest on SP 7172 (16.75 mg) and higher on MRC 9024 (21.72 mg). The male pupal weights were lower on BG II cotton cultivars (9.78–14.13 mg) as compared to larvae reared on non-Bt cotton (16.63 mg). Pupal weight of male was significantly lower on MRC 9024 (9.78mg) being at par with Ankur Jassi, SP 7172 and PAU Bt 3 in comparison to all other treatments. However, it was significantly higher on F 2228 (16.63 mg) being at par with PAU Bt 2 and RCH 776. Rajput et al (2018) also found it to be 23.46 mg on non-Bt cotton and 17.41 mg on Bt cotton. The weight of male pupae on non-Bt and Bt cotton were 21.20 and 13.10 mg, respectively (Liu et al 2001).Similarly, Liu et al (2001) reported female pupal weights to be 23.10 and 17.70 mg on non-Bt and Bt cotton, respectively.

Fecundity ranged from 16 to 51 eggs per female on various cotton cultivars. It was significantly lower on PAU Bt 3 (16.00) followed by MRC 9024, PAU Bt 2 and SP 7172 in comparison to all other treatments (Table 2). However, fecundity was higher on Ankur Jassi (51.00) being at par with F 2228 and RCH 776. Liu et al (2001) and Fand et al (2019) recorded higher fecundity. The difference in fecundity may be due to cultivar, temperature, and laboratory conditions.

The mortality of Ist instar larvae was highest in Ankur jassi and MRC 9024 (23%) being at par with PAU Bt 3 and SP 7172. The survival was highest in F 2228 being at par with PAU Bt 1 and RCH 776 (Table 3). The observations on mortality of 2nd to 4th instar larvae were in range of 3.73- 25.27 per cent. The mortality of larvae was least in F 2228 (3.73%) followed by other cultivars being higher on selective BG II cotton cultivars. The pupal mortality was significantly in range of 7.87- 20.64 per cent being lowest on F 2228 and higher on MRC 9024. These observations clearly indicate that non-Bt cotton is suitable host for development of *P. gossypiella* while BG II cotton cultivars support least survival of pink bollworm larvae and pupae.

CONCLUSION

The mean larval span was significantly lower on BG II cotton cultivars and higher on non-Bt cotton cultivar. Larval weight, pupal weight, larval and pupal survival were more on non-Bt cotton in comparison to BG II cotton cultivars. Except for fecundity, BG II cotton has significant detrimental effect on other vital parameters of *P. gossypiella*. Overall study revealed that BG II cotton cultivars, Ankur Jassi and MRC 9024 have most negative effect on various biological parameters of pink bollworm and can be recommended for cultivation under Punjab condition in integration with other measures like pheromone-based mating disruption technology and chemical components.

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Genetic Parameters in Bread Wheat (*Triticum aestivum* L. em. Thell)

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Abstract: A field study was carried out to study genetic parameters for twelve traits in bread wheat genotypes including 10 parents and their 45 F_1's produced in half-diallel fashion. There was a highly significant difference among all the genotypes for all the traits under study. PCV was somewhat greater than their corresponding GCV for all characters studied. Traits *viz.,* number of productive tillers per plant, flag leaf area, biological yield per plant, grain yield per plant, thousand grain weight, harvest index and number of grains per spike were most selection approachable as they were having higher GCV, PCV, genetic gain and moderate to high heritability in broad sense indicating pervasiveness of additive gene action, therefore, these characters would be useful for further improvement of wheat.

Keywords: Wheat, Heritability, PCV, GCV, Genetic gain

Wheat (*Triticum aestivum* L. em. Thell.) is the major staple food consumed by billions of people in the world and for that reason it has tremendous importance in the state of world nutrition and in the general welfare and national security of many countries. In India, wheat is the second most important food crop after rice both in terms of area and production. The yield is a complex polygenic inherited trait and several factors affect yield directly or indirectly, therefore, yield production fluctuates widely as a result of its interaction with the environment (Akram et al 2008). The success of any crop improvement programme depends on genetic variability, heritability and genetic gain present in the base population, based on which, the breeders may enable to plan out suitable breeding methods for further crop improvement. Characters having high heritability could easily be set with simple selection resulting in speedy progress (Mallinath et al 2004). Nevertheless, heritability is as well affected by environment so information on heritability only could not help in recognizing characters enforcing selection. Thus, the estimates of both heritability and genetic gain would be extra trustworthy circumstance for selection Heritability provides information about the extent of inheritance of the characters whereas; genetic gain helps in preparation of appropriate breeding procedures (Ranjith et al 2017). Therefore, current experiment was carried out with the aim to assess the GCV, PCV, heritability and genetic gain for 12 traits in 10 bread wheat genotypes and their 45 F_1 hybrids.

MATERIAL AND METHODS

The present research work was conducted at Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India, to estimate the level of genetic coefficient of variation, heritability and genetic gain for the purpose to ascertain and develop appropriate selection indices for the increased grain production with better quality. The material for this present investigation was produced during *Rabi* season 2017-18 and the progenies were evaluated in the next *Rabi* season 2018-19. Ten genetically diverse parents (CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…, HD 3234, PBW 692, HUW 640, DBW 189, VORB/SOKOLL, UP 2762, UP 2901, QLD 73, QLD 65) were crossed in diallel fashion excluding the reciprocals and a total of 45 crosses were developed. The parental lines along with 45 F_1's and two checks (HD 3086 and UP 2628) were planted in randomized block design in 3 replications. The row to row spacing was 20 cm and plant to plant spacing was 10 cm. Each entry was planted in one plot having 2 rows of 1 m in each replication. The seeds were dibbled manually. The recommended package of practices and cultural operations were followed. The observations were recorded on 12 traits *viz.*, days to 75% heading, days to maturity, flag leaf area (cm), number of productive tillers per plant, plant height (cm), spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight (g), biological yield per plant (g), grain yield per plant (g) and harvest index (%). Five plants were selected randomly from each entry per replication for all the traits except days to 75% heading and days to maturity which were recorded on basis of whole plot observation. The data obtained were subjected to the biometrical analysis that included analysis of variance, heritability, genetic gain. genotypic variance (σ^2g), phenotypic variance (σ^2p), genotypic coefficient of variation (GCV %), phenotypic coefficient of variation (PCV %), broad sense heritability

(h^2(bs)%) and genetic advance in per cent mean (GAM) (Singh and Chaudhary 1985).

RESULTS AND DISCUSSION

Highly significant mean squares due to genotypes for all the characters in all wheat genotypes revealed the presence of enough genetic variability in the material under study (Table 1). The mean sum of squares of the treatments were significant for all the traits studied being highest for biological yield per plant followed by harvest index, plant height, flag leaf area, thousand grain weight, number of productive tillers per plant, grain yield per plant, number of grains per spike, days to maturity, days to 75% heading, number of spikelets per spike and spike length. The highest mean performance for grain yield per plant is of parent UP 2901 and among crosses is of CAL/NH//H567.71/3/SER1/4/CAL/NH//H567 .71/5/2*KAU2/6/ × PBW 692 (Table 2). Similarly, the lowest mean performance for grain yield per plant for parent is VORB/SOKOLL and among crosses is for UP 2762 × QLD 73. The values of genotypic coefficient of variation were lower than phenotypic coefficient of variation for all characters studied reflecting the influence of environment on the expression of traits and the values of phenotypic coefficient of variation was higher than environmental coefficient of variation for all traits studied (Table 3). However, the genotypic coefficient of variation was higher than environmental coefficient of variation for all traits showing the preponderance of heritable variation except for days to maturity, spike length, number of spikelets per spike, number of grains per spike and harvest index. The highest phenotypic coefficient of variation was observed for number of productive tillers per plant (26.04%) followed by flag leaf area, biological yield per plant, harvest index, thousand grain weight and grain yield per plant while was lowest for days to maturity (1.61%). The highest genotypic coefficient of variation was observed for number of productive tillers per plant (20.27%) followed by flag leaf area, biological yield per plant, grain yield per plant and harvest index while it was lowest for days to maturity (0.97%). The amount of environmental coefficient of variation was highest for number of productive tillers per plant (16.34) followed by flag leaf area and harvest index while the lowest environmental coefficient of variation was observed for days to 75% heading (1.07%). High phenotypic and genotypic coefficient of variation was observed for traits such as number of productive tillers per plant, flag leaf area, biological yield per plant, grain yield per plant, thousand grain weight, harvest index and number of grains per spike. These results agree with the findings of Kumar et al (2014), Khan et al (2015), Fikre et al (2015) and Arya et al (2017). High heritability estimates were for traits as grain yield (91.30%) followed by thousand grain weight, biological yield per plant and days to 75% heading while lowest heritability was for number of spikelets per spike (15.00%). High heritability estimates for plant height (Tripathi et al 2011), days to 50% heading (Baranwal et al 2012), thousand kernel weight (Ashraf et al 2002), number of grains per spike (Abinasa et al 2011) are also reported by earlier researchers. Highest value genetic advance was observed for biological yield per plant (17.60%) followed by grain yield per plant, plant height, thousand grain weight, number of productive tillers per plant, harvest index, flag leaf area, number of grains per spikelet, days to 75% heading, days to maturity and number of spikelets per spike while lowest value was for spike length. High heritability coupled with high genetic advance was observed for some of the important characters such as grain yield per plant, thousand grain

Table 1. Analysis of variance for different characters in wheat

Source of variation	Mean sum of squares						
	d.f.	Days to 75 % heading	Days to maturity	Flag leaf area (cm^2)	Number of productive tillers per plant	Plant height (cm)	Spike length (cm)
Replication	2	5.99**	8.23	27.82	27.67*	12.50	3.72**
Treatments	56	6.08**	7.85**	46.34**	43.19**	54.83**	0.52**
Error	112	0.96	2.93	11.20	7.69	9.62	0.32

Source of variation	Mean sum of squares						
	d.f.	Number of spikelets per spike	Number of grains per spike	1000 grain weight (g)	Biological yield per plant (g)	Grain yield per plant (g)	Harvest index (%)
Replication	2	5.10*	66.92**	2.33	28.86	0.37	13.83
Treatments	56	2.22*	35.28**	43.49**	379.15**	41.67**	56.82**
Error	112	1.45	10.42	5.88	53.09	1.29	16.29

*, ** Significant at 5% and 1% level of significance, respectively

weight and biological yield per plant. High heritability coupled with moderate genetic advance was observed for plant height, days to 75% heading, number of productive tillers per plant, flag leaf area and harvest index while high heritability with low genetic advance was observed for rest of the characters. Selection for the traits having high genetic advance coupled with high heritability will be highly effective and have greater scope for improvement while high

Table 2. Mean performance of parents and crosses for different characters in wheat

Traits	Mean performance of parents		Mean performance of hybrids	
	Highest	Lowest	Highest	Lowest
Days to 75% heading	93.3 (UP 2628)	88.7 (UP 2726, UP 2901)	93(CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × HD 3234)	88.3 (QLD 73 × QLD 65, UP 2901 × QLD 65)
Days to maturity	136.7 (UP 2628)	130 (UP 2726)	136.7(CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…x VORB/SOKOLL)	129.7 (UP 2901 × QLD 65)
Flag leaf area (cm^2)	32.8 (HD 3234)	22.7 (HD 3086)	39.7(CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…x VORB/SOKOLL)	23.7 (UP 2901 × QLD 65)
Number of productive tillers per plant	21.3 (UP 2628, HD 3086)	9.6 (QLD 73)	23.3(VORB/SOKOLL × UP 2762)	10 (UP 2762 × QLD 73)
Plant height (cm)	101.2 (VORB/SOKOLL)	87 (QLD 65)	107.3 (DBW 189 × VORB/SOKOLL)	88.4 (HUW 640 × QLD 73)
Spike length (cm)	12.3 (DBW 189)	10.7(VORB/SOKOLL, HD 3086)	12.5 (PBW 692 × QLD 73)	10.8 (HUW 640 × QLD 73)
Number of spikelets per spike	21.3 (QLD 65)	18.4 (HD 3086)	22.7(VORB/SOKOLL × UP 2901)	19.2 (UP 2762 × QLD 73)
Number of grains per spike	72.7 (DBW 189)	60 (QLD 65)	71.3 (PBW 692 × UP 2901)	60 (DBW 189 × UP 2901)
1000 grain weight (g)	50.2 (DBW 189)	39.3 (QLD 65)	51.7 (UP 2901 × QLD 65)	36.2 (PBW 692 × QLD 65)
Biological yield per plant (g)	128.4(CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…)	89.1(VORB/SOKOLL)	125.5 (DBW 189 × QLD 65)	81.1(CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901)
Grain yield per plant (g)	48.1 (UP 2901)	31.3(VORB/SOKOLL)	49.6 (DBW 189 × QLD 65)	34.5 (PBW 692 × UP 2901)
Harvest index (%)	44.3 (HD 3234)	35.3 (UP 2762)	52.3 (UP 2901 × QLD 65)	35.5 (HUW 640 × QLD 65)

Table 3. Mean, range, coefficient of variance, heritability and genetic gain for various characters in wheat

Character	Mean	Range	PCV (%)	GCV (%)	ECV (%)	Heritability (%)	Genetic advance	Genetic value as % mean
Days to 75 % heading	91.22	88.33-93.33	1.79	1.43	1.07	64.00	2.15	2.36
Days to maturity	132.61	129.67-136.67	1.61	0.97	1.29	35.90	1.58	1.19
Flag leaf area (cm^2)	30.06	22.68-39.69	15.92	11.39	11.13	51.10	5.04	16.77
Number of productive tillers per plant	16.97	9.55-23.33	26.04	20.27	16.34	60.60	5.52	32.51
Plant height (cm)	96.94	87.0-107.26	5.13	4.01	3.20	61.10	6.25	6.45
Spike length (cm)	11.64	10.65-12.5	5.37	2.21	4.90	16.90	0.22	1.87
Number of spikelets per spike	20.43	18.44-22.67	6.40	2.48	5.90	15.00	0.41	1.98
No. of grains per spike	66.64	60.0-72.67	6.49	4.32	4.85	44.30	3.95	5.92
1000 grain weight (g)	44.92	36.17-51.67	9.55	7.88	5.40	68.10	6.02	13.40
Biological yield per plant (g)	100.15	81.13-125.49	12.70	10.41	7.28	67.20	17.60	17.58
Grain yield per plant (g)	40.85	31.30-49.62	9.40	8.98	2.78	91.30	7.22	17.68
Harvest index (%)	43.35	35.29-52.29	12.59	8.48	9.31	45.30	5.10	11.76

heritability with low genetic advance showed the preponderance of non-additive type of gene action due to high influence of the environment.

CONCLUSION

Adequate extent of variability was found in genetic material for all the traits under study. The traits *viz.,* flag leaf area, number of productive tillers per plant, plant height, thousand grain weight, biological yield per plant, grain yield per plant and harvest index showed high genetic advance in conjunction with high heritability and genotypic coefficient of variation. Therefore, these traits are the most important quantitative traits to be taken into consideration for effective selection in wheat. Low genotypic coefficient of variation, heritability and genetic advance manifested by days to maturity, spike length and number of spikelets per spike suggested that these traits cannot be relied upon for the purpose of selection.

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Seasonal influence on Population Dynamics of *Pteropus giganteus* (Chiroptera: Pteropodidae) in Agricultural and Urban Landscapes

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***Abstract*:** Present study was conducted to investigate roosting preferrence, population of Indian flying fox, *Pteropus giganteus* and its fluctuation with respect to seasonal changes at selected roosting sites in agricultural and urban landscapes for 2017-18 and 2018-19. In urban landscape, higher population of bats roosted on pinus (35.40%) followed by silver oak (19.63%), sterculia (13.73%), mango (13.21%) and eucalyptus (8.99). Interestingly, 5.10% increase in bat population was recorded in the preceeding year. In agricultural landscape, higher population of bats roosted on eucalyptus (97.52%) than banyan tree (2.48%). The 27.20% decrease in population was recorded in preceeding year due to formation of new human settlements. Migration of bats was recorded in both years during May-September which again come back during October-November. There was negative correlation of atmospheric temperature with bat population at urban (r=-0.15 to -0.28) and agricultural landscapes (r=-0.93 to -0.94), whereas positive correlation was found between relative humidity and bat population at both landscapes. Positive correlation (r=0.92 and 0.97) was in emergence time between both landscapes, which was lower in summer and higher in winter months. The study will provide baseline information to study echology, behaviour and conservation programmes of *P. giganteus*.

***Keywords*:** Fruit bat, Chiroptera, Indian flying fox, *Pteropus giganteus*, Roosting

Among mammals, bats are the second largest group which comprised 25% of all living mammals and accounts 1200 species (Bhandarkar and Paliwal 2014). They belong to order Chiroptera which is further divided into two sub-orders, megachiroptera and microchiroptera (Vyas and Upadhyay 2014). India has diversity of 12 species of megachiropteran (Srinivasulu et al 2010) and 101 microchiropteran bats (Wilson and Reeder 2005) of which only three fruit bats are commonly found throughout India, which includes Indian flying fox (*Pteropus giganteus*), fulvous fruit bat (*Rousettus leschenaultia*) and short-nosed fruit bat (*Cynopterus sphinx*). *P. giganteus* commonly known as “Indian flying fox” is largest in its group, belongs to family Pteropodidae and mainly feeds on fruits, nectar, or pollen (McConkey and Drake 2006). It is widely distributed throughout India and other regions of Asian countries (Jones and Holderied 2007). Flying foxes are very conspicuous among tree roosting bats and thus, many studies have been carried out on various aspects such as population ecology, reproductive behaviour, roosting ecology, distribution, and conservation issues (Kumar et al 2017). Population size of *P. giganteus* decreased since few decades due to many reasons like loss of habitat, climate change and shift in urban areas (Jung and Threlfall 2016). Bats are nocturnal mammals and usually live in large aggregates as colonies known as roosting sites, which may vary from hundreds to thousands depending on food availability and breeding season (Williams et al2006). They provide widespread ecological and monetary services via pollination, seed dispersal for hundreds of plant species, pest control and also regulate climate, rejuvenation of forests and nutrient cycling (Goveas et al 2006,Kunz et al2011,Maas et al 2013). Local climate, seasonal food availability and social interactions among bats are main factors responsible for evolving gregarious or solitary foliage roosting behaviour in bats. Richmond et al (1998) recorded that trees that provide better protection from environment and updrafts for easier flight are preferred for roosting. Dey et al (2013) suggested that *P. giganteus* was found to occupy different types of roosting trees at three study sites, which reflect their flexibility to occupy diverse habitat conditions and found roosted in open tree branches. Earlier studies suggested *P. giganteus* as large, noisy and squabbling colonies on trees (McKinney 2006). Under schedule V of Indian Wildlife Protection Act 1972 and International Union for Conservation of Nature and natural resources (IUCN), this species is treated as 'vermin' on the impression that it poaches ripe fruits from orchards and defecates in public places. Although the IUCN Red List of Threatened Species has classified this species as “least concerned”, the numbers of individuals are decreasing consistently primarily due to habitat loss and hunting

(Venkatesan 2007). Present study was conducted with the aim of investigating population size, roosting behaviour of *P. giganteu*s attwo selected roosting sites (agricultural and urban landscapes) and its fluctuation with respect to seasonal change for two years 2017-18 and 2018-19. Output of study may provide baseline information to study echology, behaviour and conservation programmes of *P. giganteus*.

MATERIAL AND METHODS

Selection of site: Data was collected from twodifferent roosting sites at agricultural and urban landscapes. For urban landscape, campus of Panjab University, Chandigarh(30°76" N and 76°76 E) was selected which is covered by different large trees species and human settlements (where cutting of trees and any kind of threat to bats was strictly prohibited). VillageAyali Khurd, District Ludhiana, (30°89 N and 75°75 E)was selected as agricultural landscape, where different agricultural crops like wheat, paddy, maize, sugarcane, fodders and horticultural crops like ber and guava orchards were grown during whole year, alongwith less human activity. Data was recorded for two years 2017-18 and 2018-19.Selected sites received average 500-800mm rainfall, which was not evenly distributed and most of it (70-80%) received during July, August, and September. Months were divided into seasons as per weather conditions of selected areas (Punjab, India), May and June in summer season, July and August in rainy season, September, October and November in autumn season, December, January and February in winter season, March and April in spring season, respectively.

Roosting preference and population size: Population size of *P. giganteus* at two selected roosting sites (agricultural and urban landscapes) were counted during morning hours (9-11am) at fortnight intervals (pooled on monthly basis) by using direct roost count method (Javed and Koul 2002). Each bat population was counted three times to remove any error of counting during each sampling by using binoculars (Nikon PROSTAFF 7s 10×42) to spot hiding bats in the branches of trees. For estimation of preference in roosting trees by *P. giganteus* bats among other trees, the number and trees grown around the roosted trees were counted from its 1km radius surrounding area to know variety and abundance of trees. The girth of different trees was recorded by using measuring tapeat height of 1.37m from ground surface.

Abiotic factors: Atmospheric temperature (^{0}C) and relative humidity (%) were recorded using a digital thermo-hygrometer (Vel Vetta HTC-2 Digital Tester and Clock) by holding the probe 2m above ground during study period as suggested by Dey et al(2013). Time of emergence (hours) of bats was recorded with naked eyes on watch during evening hours after sunset time (hours).Emergence time (minutes) was calculated by using formula:

Emergence time= Time of emergence of bat−time of sunset

All parameters were recorded at weekly intervals and calculated on monthly basis.

Statistical analysis: Data was put under correlation analysis to find relation between abiotic factors and bat population. Roosting preference was determined using percentages.

RESULTS AND DISCUSSION

Roosting preference and population size at urban landscape: Different trees grown in 1km radius aroundselected roosting site at urban landscape are listed in Table 1, whose number ranged from 2-87 and girth from 0.3-4.90mwherefruit bat *P. giganteus* preferred only eucalyptus (4), mango (3), sterculia (11), pinus (29), jamun (3) and silver oak (22) trees for roosting. The girth of respective trees shows that they are tall enough and give space for roosting of bats. Seasonal shifting pattern from one roosting tree to another and increase or decrease in number of *P. Giganteus* bats species were observed at study site. During 2017-18, total bat population varied from 2787-2830 individuals on different trees with mean of 2809.8 individuals. Interestingly, during winter season, bats preferred to roost on pinus (1405-1469) and eucalyptus (341-512), whereas during summer and rainy season, more bat population was recorded on mango (695-718), sterculia (428-502), jamun (369-402) and silver oak (583-685). Interestingly, during 2018-19 total bat population varied from 2877- 3002 individuals on different trees with mean of 2953 individuals and follow same trend of roosting on trees during all seasons like earlier year. Interestingly, 5.1% increase in bat population was recorded during 2018-19 as compared to 2017-18. During both years, %population of fruit bats roosted on trees (Table 2) was highest on pinus (35.40%) followed by silver oak (19.63%), sterculia (13.73%), mango (13.21%), and lowest on eucalyptus (8.99) and jamun (8.98%) as evidenced by statistical analysis of varience which concluded significant realtion between selections of trees and bat population for years 2017-19.

Roosting preference and population size at agricultural landscape: Trees grown at 1km radius area around selected roosting site in agricultural landscape are listed in Table 3, whose number ranged from 2-270 and girth from 1.1-4.7m where *P. Giganteus* fruit bat preferred to roost only on eucalyptus (20) and banyan tree (1). During 2017-18, total bat population varied from 84-494 individuals on both eucalyptus and banyan trees with mean of 346.57

Table 1. Inventory of tree species grown in and around roosting site at urban landscape

Common name	Scientific name	Order	Family	Tree number	Girth (m)
Devil tree	*Alstonia scholaris*	Gentianales	Apocynaceae	57	2.0-3.0
False ashoka	*Polyalthia longifolia*	Magnoliales	Annonaceae	20	0.9-1.5
Silver oak	*Grevillea robusta*	Proteales	Lecythidaceae	75	1.9-2.6
Bottlebrush	*Callistemon viminalis*	Myrtales	Myrtaceae	28	0.7-1.5
Eucalyptus	*Eucalyptus globules*	Myrtales	Myrtaceae	87	1.4-2.9
Weeping paper bark	*Melaleuca leucadendra*	Myrtales	Myrtaceae	11	1.2-2.4
Jamun	*Syzygium cumini*	Myrtales	Myrtaceae	13	1.6-2.4
Mango	*Mangifera indica*	Spanidales	Anacardiaceae	18	0.6-2.4
Siris	*Albizia lebbeck*	Fabales	Fabaceae	03	1.2-2.0
Sheesham	*Dalbergia sissoo*	Fabales	Fabaceae	11	1.3-1.8
Keekar	*Vachellia nilotica*	Fabales	Fabaceae	21	1.5-1.7
Jungli jalebi	*Pithecellobium dulce*	Fabales	Fabaceae	07	1.0-1.8
Champa	*Plumeria rubra*	Gentianales	Apocynaceae	13	0.4-0.9
Indian crape myrtle	*Lagerstroemia indica*	Myrtales	Lythraceae	09	0.3-0.4
Tej patta	*Cinnamomum tamala*	Laurales	Lauraceae	15	0.8-1.2
Dhak	*Butea monosperma*	Fabales	Fabaceae	10	0.6-1.1
Putijia	*Putranjivaroxburghii*	Malpighiales	Putranjivaceae	03	1.2-2.1
Amla	*Phyllanthus emblica*	Malpighiales	Phyllanthaceae	34	1.0-2.1
Rudraksh	*Elaeocarpus ganitrus*	Oxalidales	Elaeocarpaceae	02	1.5-2.8
Kend	*Diospyros melanoxylon*	Ericales	Ebenaceae	05	1.9-2.9
Sal	*Shorea robusta*	Malvales	Dipterocarpaceae	29	1.7-2.3
Elephant apple	*Dillenia indica*	Dilleniales	Dilleniaceae	04	0.9-1.9
Arjuna	*Terminalia arjuna*	Myrtales	Combretaceae	33	1.5-2.5
Bahera	*Terminalia bellirica*	Myrtales	Combretaceae	15	1.3-2.1
Harar	*Terminalia chebula*	Myrtales	Combretaceae	14	1.1-2.4
Sheoak	*Casuarina equisetifolia*	Fagales	Casuarinaceae	05	1.2-2.3
Kachnar	*Bauhinia variegate*	Fabales	Fabaceae	30	0.9-1.8
Amaltas	*Cassia fistula*	Fabales	Fabaceae	38	0.8-1.3
Pila amaltas	*Cassia glauca*	Fabales	Fabaceae	44	0.7-1.3
Gulmohar	*Delonix regia*	Fabales	Fabaceae	57	0.8-1.7
Ashoka	*Saraca asoca*	Fabales	Fabaceae	65	0.9-1.2
Imli	*Tamarindus indica*	Fabales	Fabaceae	18	0.8-1.9
Lasora	*Cordia dichotoma*	Boraginales	Boraginaceae	07	1.2-2.8
Jasmine	*Jasminum officinale*	Lamiales	Oleaceae	46	0.7-1.3
Kanak champa	*Pterospermum acerifolium*	Malvales	Malvaceae	03	0.8-1.5
Buddha coconut	*Pterygota alata*	Malvales	Malvaceae	06	0.9-1.5
Reetha	*Sapindus mukorossi*	Sapindales	Sapindaceae	09	0.5-1.2
Kusum	*Schleichera oleosa*	Sapindales	Sapindaceae	05	1.1-2.4
Litchi	*Litchi chinensis*	Sapindales	Sapindaceae	27	0.8-1.3
Indian horse chestnut	*Aesculus indica*	Sapindales	Sapindaceae	17	1.9-2.8
Kadamb	*Neolamarckia cadamba*	Gentianales	Rubiaceae	08	1.4-2.8
Neem	*Azadirachta indica*	Sapindales	Meliaceae	36	1.5-1.8
Dharek	*Melia azedarach*	Sapindales	Meliaceae	60	1.1-1.6
Pinus	*Pinus Pinus*	Pinales	Pinaceae	12	1.6-2.9
Pilkhan	*Ficus virens*	Rosales	Moraceae	05	2.0-4.9
Peepal	*Ficus religiosa*	Rosales	Moraceae	29	1.9-4.9
Banyan tree	*Ficus benghalensis*	Rosales	Moraceae	23	2.0-6.1
Fig	*Ficus carica*	Rosales	Moraceae	34	0.4-0.9
Shahtoot	*Morus alba*	Rosales	Moraceae	29	1.4-1.6
Pahadi shahtoot	*Morus nigra*	Rosales	Moraceae	08	1.2-1.7
Mahua	*Madhuca longifolia*	Ericales	Sapotaceae	02	0.6-0.9
Teak	*Tectona grandis*	Lamiales	Lamiaceae	11	1.5-2.1
Sterculia	*Sterculia alata*	Malvales	Malvaceae	55	1.7-2.6

individuals. During winter season, bats preferred to roost on eucalyptus (407-472) tree. During 2018-19, total bat population varied from 51-351 individuals on different trees with mean of 252.28 individuals. Again during winter season, more bat population was recorded on eucalyptus (324-332) tree. Interestingly, it was observed that during May to September months of both years of study period, bats migrate from their roosted trees else where for survival and come back again during October-November months. This may be due to less availability of trees surrounding the roosting site or environmental conditions. Nearly 27.20% decrease in *P. giganteus* bat population was observed during 2018-19 as compared to 2017-18. Since, during year 2018-19, a colonizer had made a new colony for human settlement in agricultural landscape near roosted site which may cause disturbance and be the reason for decrease in bat population during 2018-19. During study period 2017-19percent population of *P. giganteus* roosted on trees was highest on eucalyptus (97.52%) as compared to banyan tree (2.48%)as evidenced by statistical analysis of varience which give significant realtion between selection of trees and bat population for year (2017-19) (Table 4).

Similar observations were recorded by Khatun et al (2014) observed minimum changes in the population fluctuation (720-775 individuals) of *P. giganteus* at the Kacharighat roosting site of the Dhubri town area of Assam, during rainy period as compared to other seasons. Kumar et al(2018) suggested that bats preferred large, tall and well exposed eucalyptus trees as their roost. Roost sites are critical resources for bats as they provide a safe location with proper abiotic conditions for foraging and drinking areas (Granek 2002). Vyas and Upadhyay (2014) reported largest colony of *P. giganteus* in Gujarat having approximately 11,000 bats roosted on various tall trees. Similar

Table 2. Number of *P. giganteus* bat roosted on different tree species at urban landscape during 2017-18 and 2018-19

Trees species	Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mean population	%Population /tree speies
Pinus (29)	2017-18	1395	856	563	576	581	589	783	940	1094	1405	1469	1418	972.4	35.40
	2018-19	1421	960	814	606	577	728	984	1210	1294	1485	1501	1418	1083.1	
Silver oak (22)	2017-18	439	541	634	583	578	586	654	685	638	503	391	396	552.3	19.63
	2018-19	513	584	648	606	673	567	593	581	668	492	437	502	572.0	
Teak (11)	2017-18	276	389	431	428	446	502	474	411	446	212	181	235	369.2	13.73
	2018-19	412	390	381	525	578	585	568	476	333	328	221	285	423.5	
Jamun (3)	2017-18	109	263	402	396	369	356	376	228	212	166	133	96	258.8	8.98
	2018-19	97	317	383	390	359	328	308	255	252	97	135	156	256.4	
Eucalyptus (4)	2017-18	357	303	132	106	113	177	188	197	206	341	452	512	257.0	8.99
	2018-19	281	312	142	108	164	178	193	182	213	358	497	531	263.2	
Mango (3)	2017-18	214	435	635	718	748	613	334	333	215	182	198	173	399.8	13.21
	2018-19	153	340	618	731	596	519	297	287	221	209	174	110	354.6	
Total	2017-18	2790	2787	2797	2807	2835	2823	2809	2794	2811	2809	2824	2830	2809.6	
	2018-19	2877	2903	2986	2966	2947	2905	2943	2991	2981	2969	2965	3002	2952.9	

Table 3. Inventory of tree species grown in and around roosting site at agricultural landscape

Common name	Scientific name	Order	Family	Tree number	Girth (m)
Eucalyptus	*Eucalyptus globules*	Myrtales	Mytraceae	270	1.6-2.6
Sheesham	*Dalbergia sisso*	Fabales	Fabaceae	04	1.2-1.4
Banyan	*Populus deltoids*	Rosales	Moraceae	02	3.9-4.4
Peepal	*Ficus benghalensis*	Rosales	Moraceae	06	3.1-4.7
Kikar	*Acacia nilotica*	Fabales	Fabaceae	08	1.1-1.8
Neem	*Azadirachta indica*	Sapindales	Meliaceae	07	2.0-2.8
Mango	*Mangifera indica*	Spanidales	Anacardiaceae	11	1.8-2.7
Teak	*Tectona grandis*	Lamiales	Lamiaceae	02	1.1-1.4

observations were recorded by Louis et al (2008) where he identified 14 roosting sites; five from home gardens and two from each, temples, roadside plantations, urban park, agriculture field and a factory campus in and around Coimbatore and Palakkad (Tamil Nadu). Roosts of Indian flying fox were also observed in forest plantations of *Casurina* sp., *Acacia* sp. and indigenous tree species like *Ficus* sp., *Bahunia* sp., rain tree (*Samanea saman*) and Indian date (*T. indica*) (Chakravarthy et al 2008). During a study near Itiadoh dam reservoir near Gothangaon village, Bhandarkar and Paliwal (2014) reported an increase in population trend of roost from 410 (year 2010) to 692 (year 2014) individuals and the colony preferred to roost on *Terminalia arjuna*. The major roosting tree species used by *P. giganteus* individuals were *Caesalpinia inermis*, *Ficus bengalensis*, *Ficus religiosa* and *Eugenia jambolana*. In other study, Dey et al (2013) reported that most preferred trees by bats were *Eucalyptus* sp., *Terminalia arjuna*, *Dalbergia latifolia* and *Tamarindus indica* outside village near water bodies. Similar study carried out in Wayanad (Kerela), showed that *P. giganteus* preffered 12 tree species for their day roosting. Earlier reports indicated that *P. giganteus* also preferred to roost on different tree species like Banyan (*F. Bengalensis*), mango (*M. indica)* and tamarind (*T. indica)*, but, the roosts varied from dense foliage which provided shades and protection from open exposed areas (Vendan 2003).

Relation of atmospheric temperature and relative humidity with bat population in: Depending upon atmospheric temperature and relative humidity of surrounding environment of roosting sites, bats showed their seasonal shifting pattern on different tree species as said earlier. In urban landscape roosting site, bats preferred shaded area for roosting during year 2017-18 and 2018-19. During 2017-18, in summer season when there was high atmospheric temperature (30.9-32.7°C) and low relative humidity (39.8-60.4%) bat population recorded was 2797-2807 individuals whereas in winters, when there is low atmospheric temperature (11.8-14.7°C) and high relative humidity (77.7-82.5%) slightly higher population (2809-2830 individuals) was recorded. Similar results were observed during 2018-19 (Table 5). During 2017-18, in summer season at roosting site in agricultural landscape, when there was high atmospheric temperature (32.4-32.6°C) and low relative humidity (42.0-60.8%) no bat population was recorded due to migration whereas in winter season, when there is low atmospheric temperature (12.6-16.1°C) and high relative humidity (64.0-82.0%) higher bat population (425-494 individuals) was recorded (Table 6). Similar results were observed during 2018-19.

The study observed negative correlation of atmospheric temperature with bat population (Table 5) at both urban landscape {correlation coefficient, r=-0.15 (2017-18) and r=-

Table 4. Number of *P. giganteus* bat roosted on different tree species at agricultural landscape during 2017-18 and 2018-19

Trees species	Year	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mean population	%Population /tree speies
Eucalyptus (20)	2017-18	367	142	0	0	0	0	0	84	426	472	469	407	338.14	97.52
	2018-19	284	94	0	0	0	0	0	51	285	324	332	327	242.42	
Banyan (1)	2017-18	16	0	0	0	0	0	0	0	0	0	25	18	19.66	2.48
	2018-19	17	0	0	0	0	0	0	0	0	27	16	9	17.25	
Total	2017-18	383	142	0	0	0	0	0	84	426	472	494	425	346.57	
Total	2018-19	301	94	0	0	0	0	0	51	285	351	348	336	252.28	

Table 5. Relationship between abiotic parameters and correlation coefficient in different landscapes during 2017-18 and 2018-19

Parameters	Urban landscape				Agricultural landscape			
	2017-18		2018-19		2017-18		2018-19	
	Correlation coefficient (r)	R^2 value	Correlation coefficient (r)	R^2 value	Correlation coefficient (r)	R^2 value	Correlation coefficient (r)	R^2 value
Atmospheric temperature (^{0}C)	-0.15	+0.02	-0.28	+0.07	-0.93	+0.86	-0.94	+0.88
Relative humidity (%)	+0.65	+0.42	-0.05	+0.002	+0.19	+0.03	+0.35	+0.12
*Emergence time (minutes)	--	--	--	--	+0.92	+0.84	+0.97	+0.94

*Emergence time (minutes) was compared during 2017-18 and 2018-19 between bothlandscapes

0.28 (2018-19)} and agricultutral landscape {r=-0.93(2017-18) and r=-0.94 (2018-19)}. A positive correlation was between relative humidity and bat population at agricultutral landscape {r=+0.19 (2017-18) and r=+0.35 (2018-19)} and urban landscape {r=+0.65 (2017-18), r=-0.05 (2018-19)}. In urban landscape, there was abundance of big trees all around which gives congenial environmental conditions throughout year due to which there was less variation in bat population. So, bats do not migrate from the campus site as there were human settlements nearby also. This may be a reason that 5.1% increase in bat population was recorded at this site during the preceeding year. Interestingly, at agricultutral landscape, it was observed that during summer season when there is high atmospheric temperature (31.6-32.4°C) and lowest relative humidity (42.0-44.0%), bats migrate from their roosted trees to a long distance and come back again during October-November which may be due to less availability of trees surrounding the roosting site. At agricultural landscape, 27.20% decreases in bat population was recorded during the preceeding year. Neuweiler (2000) observed that in active state, fruit bats could maintain their body temperatures between 35 and 39^{0}C. However, mention may be made that a small fraction of the bat population from the present study location made local migrations to take shelter and returned to their home of roosting site when environmental conditions become congenial, which may be the reason for lower *P. giganteus* population during summer months. Climate change has been predicted to have profound impacts on the natural environment (Laurence 2010) and the present study has provided an example of how high temperature might affect the population of fruit bats. About 48% declines in *P. giganteus* population from a roosting site in Assam (India) had been reported by Ali (2010) during his 10 years of study from 2001 to 2010 due to change in abiotic factors.

Emergence time of bats: Time of sunset hour and time of emergence of *P. giganteus* bats has strong association with their emergence time for foraging activity (searching of food and water). Emergence time of bats varied significantly and follow same trend during both years of study period and landscapes. In urban landscape (Fig. 1), emergence time ranged from 21.5-46.5minutes, which was lowest in summer (21.5-24.0 minutes) and higher in winter months (40.5-46.5 minutes). Similarly, in agricultural landscape, emergence time of bats varied significantly and ranged from 19.5-45.0minutes which was lowest in summer (19.5-22.0minutes) and higher in winter months (41.0-45.0 minutes). Among both landscapes, there was non significant difference between values corresponding to months and seasons. A positive correlation in emergence time was recorded between urban and agricultural landscapes (r=0.92-0.97). In both

Fruit bat roosting over different trees

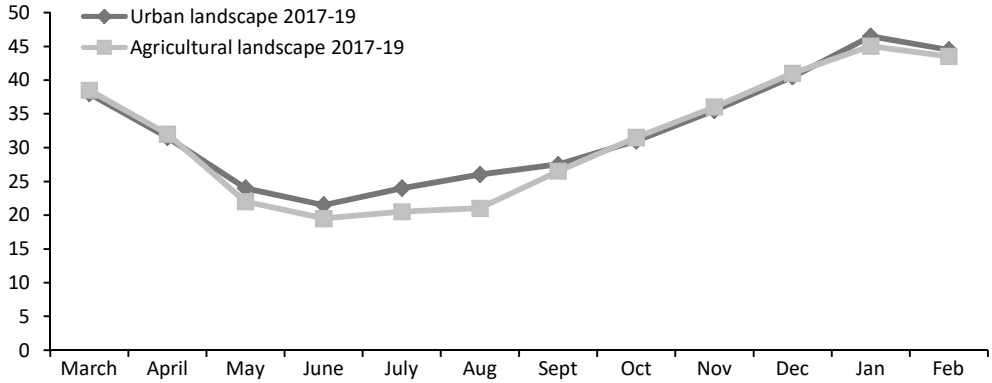

Fig. 1. *P. giganteus* emergence time (minutes) in urban and agricultural landscapesduring 2017-18 and 2018-19

landscapes, as move from June to January, emergence time of fruit bats increases and then starts decreasing from February to May. This lowest difference during summer may be due to more water requirements due to high atmospheric temperature. Time of emergence in bats is an adaptive behaviour to meet foraging needs and decreasing risks of predation and competition. According to a study, Indian Flying Fox emerged 30 minutes after sunset during rainy season and in summer season emerged 50minutes after sunset (Duverge et al 2000). In a study during October, Walton and Trowbridge (1983) reported that the time of departure of *P. giganteus* bats from the roost was 18:00 hrs and the emergence of *P. giganteus* mostly occurs 10 to 20 minutes after sunset. Jacobsen and Duplessis (1976) reported that in Africa, the time of emergence of *R. aegyptiacus* was usually 20 to 40minutes after sunset and may be to avoid dehydration. Gaisler (1963) reported that subtropical bats (*Rhinolophus hipposideros*) leave the roost relatively at the same time in relation to sunset throughout the year.

CONCLUSION

In urban landscape, percent population of fruit bats roosted was highest on pinus followed by silver oak, sterculia, mango, eucalyptus and jamun and 5.1% increase in bat population was recorded in the preceeding year, whereas in agricultutral landscape % bat population roosted was highest on eucalyptus and banyan trees and 27.20% decrease in bat population was recorded in the preceeding year due to formation of new human settlements. Interestingly, migration of bats was recorded for both years during May-September in agricultural landscape which again comes back during October-November. Negative correlation of atmospheric temperature and positive correlation of relative humidity with bat population was recorded at both landscapes. Positive correlation was recorded between emergence time in urban and agricultural landscapes, which was lower in summer and higher in winter months.

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Winter Assemblage of Avifauna at Chawandiya, Bhilwara, Rajasthan, India

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***Abstract*:**Winter assemblage of avifauna for migratory birds was observed at Chawandiya pond in the region of Bhilwara, Rajasthan, during the winter season (January 2023). The 102 species of birds from 39 families were identified. Most of the families were represented by less than 10 species except family Anatidae. These include 69 residential and 33 winter visitors species. The 42 species of water dependent birds was observed. Among these bird species, 35 were omnivorous, 34 carnivorous, 25 insectivorous, 05 granivorous, 02 frugivorous and 01 nectivorous respectively. For the conservation of avifauna, creation of buffer zone and strict implementation of regulation is needed.

***Keywords*:** Avifauna, Wetland birds, Winter visitors, Chawandiya

Birds play key role the ecosystem as prospective pollinators and scavengers, and are also referred as bio-indicators. India, a mega-diversity hot-spot, is home to more than 1301 bird species, or 13% of all bird species worldwide (Ali 2012). A checklist of birds of India which included 1263 species of birds out of which 61(4.8%) are endemic to India (Praveen et al 2016). In Rajasthan, checklist of 183 birds have been reported from Sariska Tiger Reserve, Rajasthan, India (Shahabuddin et al 2006). More than 350 species of birds which include 42 species of raptors and 9 species of owls have been reported from Keoladeo Ghana National Park (Mathur et al 2009). The 181 bird species were recorded from Jhalawar forest division (Yadav and Chauhan 2018). The avian diversity was lower during summer (155 bird species) and higher in winter (Yadav and Chauhan 2018). Total 114 bird species belonging to 12 orders and 42 families were recorded from Shahpur Campus of the Central University, Himachal Pradesh and the surrounding area (Kumar 2021). Total 128 bird species belonging to 49 and 15 orders were recorded from Agricultural Fields of Ayodhya district, Uttar Pradesh (Yashmita and Ulman 2022). Wetlands are essential sites for waders to feed and lay their eggs, as well as for fish-eating birds and migrating birds of winter. The relationship between birds and wetlands is dependent on the quantity, quality, and depth of water as well as the availability of food, shelter and predators. The present study is focused on preparing the checklist of birds during winter season.

MATERIAL AND METHODS

Study area: Bhilwara is located at 25.35° N latitude and 74.63°E longitude covering geographical area of 10,455 sq km. It has an average elevation of 421 meters (1381 feet). It falls between the districts of Ajmer (in north) and Chittorgarh, Udaipur (in south). Chawandiya village (25°19'818"N & 74°46'516"E), situated 15 km away from Bhilwara, is selected for the study of avifaunal diversity.

Methodology: For the study of avifauna, direct observation method was applied. Bird Census Techniques (Colin 1993) such as line-transect method, focal method, Ad-libitum method, visual encounter method, scan-sampling method and indirect method etc. were used for survey of different bird species. Regular visits were made in morning hours (6 to 8 am) and evening hours (4 to 8 pm) at Chawandiya. Photographic record was maintained using NIKON D500 camera for further identification. All birds sighted or heard, including those in flight were counted and recorded. The birds inhabiting and visiting the area under study were observed with naked eye or through vanguard binocular (16X50) whenever found necessary to record the data from a long distance in order to avoid any interference.

RESULTS AND DISCUSSION

The checklist of birds, sighted at the Chawandiya during the winter season, includes 102 species from 39 families. Members of Ardeidae, Rallidae and Sturnidae families contributes maximum avifauna of the pond throughout year. Most of the families were represented by less than 10 species except Anatidae (Fig. 1). Almost members of Anatidae, Scolopacidae, Motacillidae and Pelecanidae families are winter visitors. Based on their preferred foods, the birds in the

Table 1. List of bird sighted

Name	Zoological name	Food habit	Residential status	IUCN status	No.
Family: Phasianidae					
Grey Francolin	*Francolinus pondicerianus*	Omnivorous	R	LC	2
Indian Peafowl	*Pavo cristatus*	Omnivorous	R	LC	4
Family: Anatidae					
Northern Pintail	*Anas acuta*	Omnivorous	WV	LC	15
Northern Shoveler	*Anas clypeata*	Omnivorous	WV	LC	58
Common Teal	*Anas crecca*	Omnivorous	WV	LC	56
Eurasian Wigeon	*Anas penelope*	Omnivorous	WV	LC	8
Spot-billed Duck	*Anas poecilorhyncha*	Omnivorous	R	LC	45
Garganey	*Anas querquedula*	Omnivorous	WV	LC	5
Gadwall	*Anas strepera*	Omnivorous	WV	LC	57
Common Pochard	*Aythya ferina*	Omnivorous	WV	VU	158
Red-crested Pochard	*Netta rufina*	Omnivorous	WV	LC	5
Tufted Duck	*Aythya fuligula*	Omnivorous	WV	LC	5
Ferruginous Pochard	*Aythya nyroca*	Omnivorous	WV	NT	4
Comb duck	*Sarkidiornis melanotos*	Omnivorous	R	LC	8
Ruddy Shelduck	*Tadorna ferruginea*	Omnivorous	WV	LC	10
Family: Podicipedidae					
Little Grebe	*Tachybaptus ruficollis*	Carnivorous	R	LC	54
Family: Ciconiidae					
Painted Stork	*Mycteria leucocephala*	Carnivorous	R	NT	560
Family: Threskiornithidae					
Eurasian Spoonbill	*Platalea leucorodia*	Carnivorous	R	LC	14
Glossy Ibis	*Plegadis falcinellus*	Carnivorous	WV	LC	1
Red-naped Ibis	*Pseudibis papillosa*	Carnivorous	R	LC	1
Family: Ardeidae					
Grey Heron	*Ardea cinerea*	Carnivorous	WV	LC	3
Purple Heron	*Ardea purpurea*	Carnivorous	R	LC	1
Indian Pond-Heron	*Ardeo lagrayii*	Carnivorous	R	LC	22
Cattle Egret	*Bubulcus ibis*	Carnivorous	R	LC	14
Great Egret	*Casmerodius albus*	Carnivorous	R	LC	15
Little Egret	*Egretta garzetta*	Carnivorous	R	LC	13
Intermediate Egret	*Mesophoyx interment*	Carnivorous	R	LC	2
Black-crowned Night- Heron	*Nycticorax*	Carnivorous	R	LC	8
Family: Pelecanidae					
Great White Pelican	*Pelecanus onocrotalus*	Carnivorous	WV	LC	32
Dalmatian Pelican	*Pelecanus crispus*	Carnivorous	WV	VU	8
Family: Phalacrocoracidae					
Great Cormorant	*Phalacrocorax carbo*	Carnivorous	WV	LC	1
Indian Cormorant	*Phalacrocorax fuscicollis*	Carnivorous	R	LC	357
Little Cormorant	*Phalacrocorax niger*	Carnivorous	R	LC	28
Family: Accipitridae					
Black-winged Kite	*Elanus caeruleus*	Carnivorous	R	LC	1

Cont...

Table 1. List of bird sighted

Name	Zoological name	Food habit	Residential status	IUCN status	No.
Shikra	*Accipiter badius*	Carnivorous	R	LC	1
Crested Serpent-Eagle	*Spilornis cheela*	Carnivorous	R	LC	1
Family: Rallidae					
Common Coot	*Fulica atra*	Omnivorous	R	LC	84
White-breasted Water hen	*Amaurornis phoenicurus*	Omnivorous	R	LC	9
Common Moorhen	*Gallinula chloropus*	Omnivorous	R	LC	8
Grey headed Swamp hen	*Porphyrio*	Omnivorous	R	LC	14
Family: Burhinidae					
Great Thick-knee	*Burhinus recurvirostris*	Carnivorous	R	NT	2
Family: Charadriidae					
Little Ringed Plover	*Charadrius dubius*	Carnivorous	R	LC	6
Red-wattled Lapwing	*Vanellus indicus*	Omnivorous	R	LC	12
Family:Recurvirostridae					
Black-winged Stilt	*Himantopus*	Omnivorous	R	LC	20
Family: Scolopacidae					
Little Stint	*Calidris minuta*	Insectivorous	WV	LC	22
Temminck's Stint	*Calidris temminckii*	Insectivorous	WV	LC	1
Common Snipe	*Gallinago*	Insectivorous	WV	LC	3
Black -tailed Godwit	*Limosa*	Omnivorous	R	NT	5
Wood Sandpiper	*Tringa glareola*	Insectivorous	WV	LC	10
Green Sandpiper	*Tringa ochropus*	Insectivorous	WV	LC	12
Marsh Sandpiper	*Tringa stagnatilis*	Insectivorous	WV	LC	4
Common Sandpiper	*Tringa hypoleucos*	Insectivorous	WV	LC	15
Common Redshank	*Tringa totanus*	Insectivorous	WV	LC	6
Family: Laridae					
Whiskered Tern	*Chlidonias hybridus*	Carnivorous	WV	LC	6
River Tern	*Sterna aurantia*	Carnivorous	R	NT	16
Family: Columbidae					
Rock Pigeon	*Columba livia*	Granivorous	R	LC	50
Spotted Dove	*Streptopelia chinensis*	Granivorous	R	LC	2
Eurasian Collared Dove	*Streptopelia decaocto*	Granivorous	R	LC	25
Laughing Dove	*Streptopelia senegalensis*	Granivorous	R	LC	26
Red Collared Dove	*Streptopelia tranquebarica*	Granivorous	R	LC	1
Family: Psittacidae					
Rose-ringed Parakeet	*Psittacula krameri*	Frugivorous	R	LC	33
Family: Cuculidae					
Asian Koel	E*udynamys scolopaceus*	Omnivorous	R	LC	1
Southern Coucal	*Centropus sinensis*	Omnivorous	R	LC	1
Family: Strigidae					
Spotted Owlet	*Athene brama*	Carnivorous	R	LC	3
Family: Upupidae					
Eurasian Hoopoe	*Upupa epops*	Insectivorous	R	LC	4
Family: Coraciidae					
Indian Roller	*Coracias benghalensis*	Carnivorous	R	LC	5
Family: Alcedinidae					
Common Kingfisher	*Alcedo atthis*	Carnivorous	R	LC	3
White-throated Kingfisher	*Halcyon smyrnensis*	Carnivorous	R	LC	6
Pied Kingfisher	*Ceryl erudis*	Carnivorous	R	LC	1

Cont...

Table 1. List of bird sighted

Name	Zoological name	Food habit	Residential status	IUCN status	No.
Family: Meropidae					
Little Green Bee-eater	*Merops orientalis*	Insectivorous	R	LC	54
Family: Bucerotidae					
Indian Grey-Hornbill	*Ocyceros birostris*	Omnivorous	R	LC	2
Family :Ramphastidae or Megalaimidae					
Coppersmith Barbet	*Megalaima haemacephala*	Omnivorous	R	LC	2
Family: Picidae					
Black-rumped Flameback	*Dinopium benghalense*	Insectivorous	R	LC	1
Family: Laniidae					
Long-tailed Shrike	*Lanius schach*	Carnivorous	R	LC	4
Isabelline shrike or Daurian shrike	*Lanius isabellinus*	Carnivorous	WV	LC	2
Family: Dicruridae					
Black Drongo	*Dicrurus macrocercus*	Insectivorous	R	LC	8
Family: Corvidae					
Jungle Crow	*Corvus culminatus*	Carnivorous	R	LC	1
House Crow	*Corvus splendens*	Carnivorous	R	LC	6
Rufous Treepie	*Dendrocitta vagabunda*	Omnivorous	R	LC	2
Hirundinidae					
Dusky Crag-Martin	*Hirundo concolor*	Insectivorous	R	LC	2
Wire-tailed Swallow	*Hirundo smithii*	Insectivorous	R	LC	16
Family: Pycnonotidae					
Red-Vented Bulbul	*Pycnonotus cafer*	Frugivorous	R	LC	20
Family: Cisticolidae					
Plain Prinia	*Prinia inornata*	Insectivorous	R	LC	2
Ashy Prinia	*Prinia socialis*	Insectivorous	R	LC	2
Family: Sylviidae					
Lesser White throat	*Sylvia curruca*	Insectivorous	WV	LC	1
Family: Timaliidae					
Large Grey Babbler	*Turdoides malcolmi*	Omnivorous	R	LC	14
Jungle Babbler	*Turdoides striatus*	Omnivorous	R	LC	22
Family: Sturnidae					
Bank Myna	*Acridotheres ginginianus*	Omnivorous	R	LC	25
Common Myna	*Acridotheres tristis*	Omnivorous	R	LC	30
Asian Pied Starling	*Sturnus contra*	Omnivorous	R	LC	8
Brahminy Starling	*Sturnus pagodarum*	Omnivorous	R	LC	15
Family: Muscicapidae					
Indian Robin	*Saxicoloides fulicata*	Insectivorous	R	LC	8
Oriental Magpie-Robin	*Copsychus saularis*	Insectivorous	R	LC	6
Red-breasted Flycatcher	*Ficedula parva*	Insectivorous	WV	LC	1
Family: Necterinidae					
Purple Sunbird	*Nectarinia asiatica*	Nectivorous	R	LC	8
Family: Passeridae					
Chestnut-shouldered Petronia	*Petronia xanthocollis*	Omnivorous	R	LC	6
Family: Motacillidae					
Tree Pipit	*Anthus trivialis*	Insectivorous	WV	LC	2
White Wagtail	*Motacilla alba*	Insectivorous	WV	LC	32
Grey Wagtail	*Motacilla cinerea*	Insectivorous	WV	LC	1
Citrine Wagtail	*Motacilla citreola*	Insectivorous	WV	LC	6
Yellow Wagtail	*Motacilla flava*	Insectivorous	WV	LC	8
White-browed Wagtail	*Motacilla maderaspartensis*	Omnivorous	R	LC	5
Total					2315

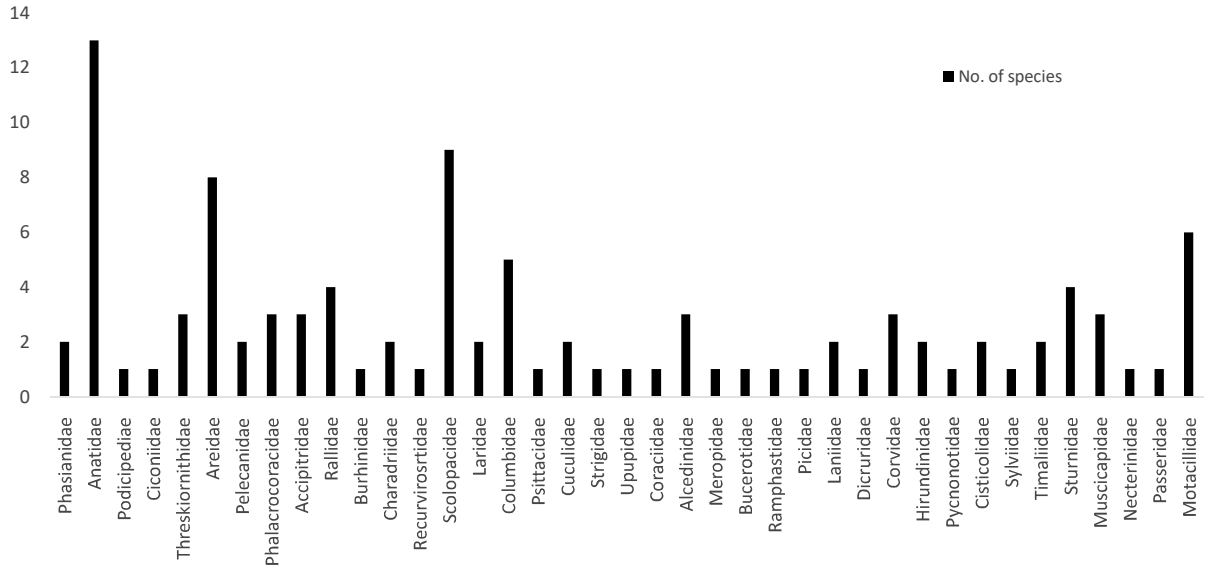

Fig. 1. Number of species in each family

current study were divided into seven categories. Among these bird species 35 were omnivorous, 34 Carnivorous, 25 Insectivorous, 05 Granivorous, 02 Frugivorous, 01 Nectivorous respectively (Table 1).

CONCLUSION

During the winter, migratory species used the pond for foraging. Chawandiya pond (also known as mataji pond) is an important wintering area for diving ducks and fish-eating birds. The best level of protection from predators is also offered by the trees and partially submerged shrubs. This pond has many trees of *Acacia nilotica* stand in and near water which is excellent site for perching and nesting. During the surveys, threats to birds diversity were noted such as habitat destruction, urbanization, human disturbance, cutting of trees, fishing and availability of water. The dense forest surrounding the wetland should be protected by the villagers. For irrigation, there should be limited use of water from this wetland.

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Avifaunal Diversity around Urban and Rural Areas of District Patiala, Punjab, India

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***Abstract*:** The present study was conducted for assessing the avifaunal diversity in district Patiala, Punjab. Patiala being the princely state, many thick forest patches had been conserved by the Royals of Patiala. These sites are still protected but due to unprecedented rise of human population have consequently started altering natural habitat which adversely affects biodiversity. Survey includes Patiala, Nabha, Ghanaur, Rajpura, Sunam and Patran owning eight protected areas and five sanctuaries. Total 204 bird species belonging to 18 orders and 58 families along with other details like their feeding habits, occurrence, distribution status and conservation status have been recorded. The majority of the birds found during survey were listed under Least Concern category of Red List of IUCN, but few of them were listed under vulnerable notably Indian Spotted Eagle (*Clanga hastate*), White-Necked Stork (*Ciconia episcopus*), Common Pochard (*Aythya ferina*), near threatened are Black-tailed Godwit (*Limosa limosa*), Painted Stork (*Mycteria leucocephala*), Black Headed White Ibis (*Threskiornis melanocephalus*), Oriental Darter (*Anhinga melanogaster*), Alexandrine Parakeet (*Psittacula eupatria*) and endangered species Steppe Eagle (*Aquila nipalensis*), Egyptian Vulture (*Neophron percnopterus*) categories. The Passeriformes order is the most prevalent, followed by the Charadriiformes, Anseriformes, Pelecaniformes and Accipitriformes .

***Keywords*:** Avian diversity, Patiala, Rural, Urban, Threatened

Birds are ideal indicators to evaluate environmental health and can be found in many habitats within human settlements, Indian subcontinent harbor 1408 bird species which are considered to be 13% of total birds of the world (Praveen et al 2020). However, most of the work regarding bird diversity is limited to natural and protected areas (Bal and Dua 2010, Mehta 2014, Brraich and Kaur 2016, Brraich and Singh 2021a, Singh and Brraich 2021) and these semi-natural unprotect urban areas get very little attention by researchers hence, remains undocumented. Most of these semi-natural landscapes in urban and semi-urban areas of human settlements have diverse flora and fauna which usually remains unexplored. Rapid increase in human population lead to occupy maximum space by humans, and alter these natural habitats to make suitable for ourselves, but their consequences are ultimately faced by wild creature especially birds, as they are among the most common species that are affected by minor changes (Brambilla et al 2010). Rise in noise level, habitat fragmentation, collision with automobiles, electric shocks from electric wires and other sources are most common disturbances which cause loss of avian diversity (Ortega 2012, Francis et al 2012, Boukrouma et al 2017, Perillo et al 2017, Bernat-Ponce et al 2021). There are many studies worldwide as in to understand the distribution of birds in urban non-protected habitats Cornel is and Hermy (2004), Tryjanowski et al (2017), Callaghan et al (2018), Lee et al (2021) but in India, only a few studies are reported (Kheraetal 2009, Turaga 2015, Brraich and Singh 2021b). For conservation of bird species, it is important to recognize the bird diversity present in particular area and then to start affective conservation measures. Hitherto, no previous report is available on the avian diversity of district Patiala, hence the current study provides large overview of avian diversity and set a baseline to the further studies.

MATERIAL AND METHODS

Study area: Geographically district Patiala is located in between 29°49'-30°40' North latitudes and 75°58'-76°48' East longitudes with 3218 sq.km geographical area having tropical, semi-arid, hot and subtropical monsoon climatic conditions and experience five seasons i.e. summer, rainy, autumn, winter and spring. Study area is divided into six blocks such as (Patiala, Nabha, Ghanaur, Rajpura, Sunam and Patran) which also includes eight protected areas locally called Birs (Kharabgarh, Miranpur and Ghogpur, Kule Majra, Majal, Sanaur, Bahadurgarh and Mallehwal) and five sanctuaries (Bhuner Heri, Moti Bhag, Mehas, Dosanj and Bhadson). These areas have diverse range of habitats and they include forests, woodlands, canals, village ponds,

agricultural lands, and some temporary or permanent small water bodies. Major water bodies include River Ghaggar, Badi Nadi, Sirhind Canal and their extensions. Large Woodland are as mainly include protected areas and sanctuaries beside that, public parkland, dense vegetation along rivers, avenue vegetation was also explored.

Methods: During the study, bimonthly surveys were conducted from 2018 to 2020 by visual encounter surveys, point count, and line transects method in visited areas, for observation and data collection (Bibby et al 2000). Photography of birds was done during the survey with DSLR cameras Conon EOS 7D (100-400mm zoom lens), Canon (1200D) (75-300mm zoom lens) and binocular (Olympus 8-16*40 zoom DPS-I) were used for spotting, and field notes were prepared, followed by identification of birds using field guides (Ali and Ripley 1983, Grimmett et al 2012) and classification was followed according to Clements et al (2021). On the basis of frequency of their occurrence, they were divided to very common (recorded in more than 45%), common (25% to 44%), uncommon (10% to 24%) and rare (recorded once or twice) (McKinnon and Philips 1993).

RESULTS AND DISCUSSION

The district Patiala support 204 species of birds which belong to 18 orders and 58 families. Most of the birds were under least concern category of Red list of IUCN. Five species belongs to near threatened category which were Black-tailed Godwit (*Limosa limosa*), Painted Stork (*Mycteria leucocephala*), Black Headed White Ibis (*Threskiornis melanocephalus*), Oriental Darter (*Anhinga melanogaster*), Alexandrine Parakeet (*Psittacula eupatria*) and three species falls under vulnerable category i.e. Indian Spotted Eagle (*Clanga hastate*), White-Necked Stork (*Ciconia episcopus*), Common Pochard (*Aythya ferina*) and two species were reported under endangered category i.e. Steppe Eagle (*Aquila nipalensis*), Egyptian Vulture (*Neophron percnopterus*) (Table 1). Egyptian Vulture found breeding in Patiala from last few years. Order wise analysis shows that, the order Passeriformes was dominant (28 families with 91 species of birds) followed by Charadriiforms with 7 families (25 species), Anseriformes 1 family (16 species). Pelecaniformes 2 families (14 species), Accipitriformes one family (12 species).

Feeding data reveals that 41.68% were insectivorous followed by 22.54% omnivorous birds, 22.54% carnivorous, 6.86% were grainivorous, 3.92% were frugivorous and 3.43% were herbivorous. Based on their distribution in Punjab 42.64% of birds are common resident of Punjab, 1.53% of birds are common passage migrant, 1.53% of birds are common summer visitor, 7.17% are common winter visitor, 2.05% are locally common resident, 1.53% of birds are locally common winter visitor, 3.58% birds species are not common passage migrant, 13.84% of birds are not common resident, 5.12% of birds are not common summer visitor, 17.94 % of birds are not common winter visitor, 1.02 % of birds are not common winter visitor and passage migrant, 2.05% of birds are vagrant in Punjab. Most of birds fall under common and very common category (35.78 and 29.90% respectively) followed by 19.16% and 11.76% in uncommonand rare category.

The order wise analysis shows that Passeriformes birds were dominates and insectivorous birds were dominating over others on the basis of their feeding. Similar observations have been also reported from Khajjiar lake, district Chamba Himachal Predesh**,** Nangal Wetland Ramsar site Punjab, and Chillavaripalli and Ellutla Reserve forests Reserve Anantapur district of Andhra Pradesh, respectively (Singh and Banyal 2013, Brraich and Kaur 2016, Subramanyam and Khan 2016, Kukreti 2021). Breeding pair of Egyptian Vulture was spotted during the survey (Kumar et al 2020).The maximum species were from forest areas, woodlands and water bodies (village ponds and rivers) followed by agriculture land and least from the residential areas. Species spotted in residential area were common at all the sites. Several factors like size of habitat, food availability and human interference determine the species diversity and abundance. Similarly, as per existing literature on bird diversity, rural areas always show higher species diversity then the urban with increase in urbanization, bird diversity become more distinct and homogenous between urban areas. As urbanization cause habitat fragmentation and alter their original state and because biodiversity loses, but at the same time also offers foraging and cover to some bird

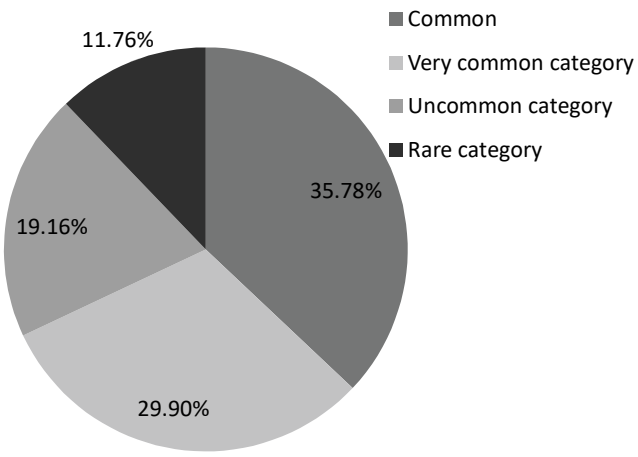

Fig. 1. Relative abundance of birds in district Patiala

Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
Order: Accipitriformes						
Black Kite	*Milvus lineatus* (Boddaert 1783)	Accipitridae	Carnivorous	cr	Very common	Least concern
Black-shouldered Kite	*Elanus caeruleus* (Desfontaines 1789)	Accipitridae	Carnivorous	nr	Common	Least concern
Booted Eagle	*Hieraaetus pennatus* (Gmelin 1788)	Accipitridae	Carnivorous	np	Uncommon	Least concern
Egyptian Vulture	*Neophron percnopterus* (Linnaeus 1758)	Accipitridae	Carnivorous	nr	Common	Endangered
Eurasian Sparrowhawk	*Accipiter nisus* (Linnaeus 1758)	Accipitridae	Carnivorous	nw	Uncommon	Least concern
Shikra	*Accipiter badius* (Gmelin 1788)	Accipitridae	Carnivorous	cr	Very common	Least concern
Steppe Eagle	*Aquila nipalensis* Hodgson 1833	Accipitridae	Carnivorous	nw	Rare	Endangered
Indian Spotted Eagle	*Clanga hastate* (Pallas 1811)	Accipitridae	Carnivorous	nr	Uncommon	Vulnerable
Bonelli's Eagle	*Hieraaetus fasciatus* (Vieillot 1822)	Accipitridae	Carnivorous	nw	Uncommon	Least concern
Oriental Honey-Buzzard	*Pernis ptilorhynchus* (Temminck 1821)	Accipitridae	Carnivorous	lcr	Uncommon	Least concern
Common Buzzard	*Buteo* Linnaeus 1758	Accipitridae	Carnivorous	nw	Uncommon	Least concern
Crested Serpent-Eagle	*Spilornis cheela* (Latham 1790)	Accipitridae	Carnivorous	nr	Uncommon	Least concern
Order: Anseriformes						
Bar-headed Goose	*Anser indicus* (Latham 1790)	Anatidae	Herbivorous	lcw	Common	Least concern
Comb Duck	*Sarkidiornis melanotos* (Pennant 1769)	Anatidae	Omnivorous	ns	Very common	Least concern
Common Pochard	*Aythya ferina* (Linnaeus 1758)	Anatidae	Omnivorous	cw	Common	Vulnerable
Common Teal	*Anas crecca* Linnaeus 1758	Anatidae	Omnivorous	cw	Common	Least concern
Cotton Teal	*Nettapus coromandelianus* (Gmelin 1789)	Anatidae	Omnivorous	ns	Rare	Least concern
Eurasian Wigeon	*Anas penelope* Linnaeus 1758	Anatidae	Herbivorous	nw	Uncommon	Least concern
Gadwall	*Anas strepera* Linnaeus 1758	Anatidae	Omnivorous	cw	Common	Least concern
Garganey	*Anas querquedula* Linnaeus 1758	Anatidae	Omnivorous	cp	Uncommon	Least concern
Greylag Goose	*Anser* (Linnaeus 1758)	Anatidae	Herbivorous	cw	Common	Least concern
Spot-billed Duck	*Anas poecilorhyncha* J.R. Forester 1781	Anatidae	Herbivorous	cr	Very common	Least concern
Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield 1821)	Anatidae	Omnivorous	nw	Very common	Least concern
Northern Shoveller	*Anas clypeata* Linnaeus 1758	Anatidae	Omnivorous	cw	Very common	Least concern
Northern Pintail	*Anas acuta* Linnaeus 1758	Anatidae	Herbivorous	nw	Very common	Least concern
Red-crested Pochard	*Netta rufina* (Pallas 1773)	Anatidae	Herbivorous	lcw	Common	Least concern
Brahminy Shelduck	*Tadorna ferruginea* (Pallas 1764)	Anatidae	Omnivorous	lcw	Common	Least concern
Common Shelduck	*Tadorna* (Linnaeus 1758)	Anatidae	Omnivorous	nw	Uncommon	Least concern
Order: Apodiformes						
House Swift	*Apus affinis* (J.E. Gray 1830)	Apodidae	Insectivorous	cr	Common	Least concern
Alpine Swift	*Tachymarptis melba* (Linnaeus 1758)	Apodidae	Insectivorous	nr	Common	Least concern
Order: Charadriiformes						
Black-tailed Godwit	*Limosa* (Linnaeus 1758)	Scolopacidae	Carnivorous	nwp	Rare	Near
Black-winged Stilt	*Himantopus* (Linnaeus 1758)	Recurvirostridae	Insectivorous	cr	Very common	Least concern
Common Redshank	*Tringa totanus* (Linnaeus 1758)	Scolopacidae	Insectivorous	nw	Very common	Least concern
Common Sandpiper	*Actitis hypoleucos* Linnaeus 1758	Scolopacidae	Insectivorous	nw	Very common	Least concern
Common Snipe	*Gallinago* (Linnaeus 1758)	Scolopacidae	Insectivorous	nw	Very common	Least concern
Dunlin	*Calidris alpina* (Linnaeus 1758)	Scolopacidae	Insectivorous	nw	Uncommon	Least concern
Stone-Curlew	*Burhinus oedicnemus* (Linnaeus 1758)	Burhinidae	Insectivorous	cr	Common	Least concern

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Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
Green Sandpiper	*Tringa ochropus* Linnaeus 1758	Scolopacidae	Carnivorous	nw	Common	Least concern
Common Greenshank	*Tringa nebularia* (Gunner 1767)	Scolopacidae	Carnivorous	nw	Common	Least concern
Small Pratincole	*Glareola lactea* Temminck 1820	Glareolidae	Insectivorous	nr	Uncommon	Least concern
Little Ringed Plover	*Charadrius dubius* Scopoli 1786	Charadriidae	Insectivorous	np	Common	Least concern
Little Stint	*Calidris minuta* (Leisler 1812)	Scolopacidae	Insectivorous	nw	Common	Least concern
Marsh Sandpiper	*Tringa stagnatilis* (Bechstein 1803)	Scolopacidae	Insectivorous	nw	Common	Least concern
Pheasant-tailed Jacana	*Hydrophasianus chirurgus* (Scopoli 1786)	Jacanidae	Omnivorous	nr	Common	Least concern
Pied Avocet	*Recurvirostra avosetta* Linnaeus 1758	Recurvirostridae	Insectivorous	nwp	Uncommon	Least concern
Red-wattled Lapwing	*Vanellus indicus* (Boddaert 1783)	Charadriidae	Insectivorous	cr	Very common	Least concern
Ruff	*Philomachus pugnax* (Linnaeus 1758)	Scolopacidae	Omnivorous	np	Very common	Least concern
Spotted Redshank	*Tringa erythropus* (Pallas 1764)	Scolopacidae	Insectivorous	nw	Common	Least concern
Temminck's Stint	*Calidris temminckii* (Leisler 1812)	Scolopacidae	Insectivorous	nw	Uncommon	Least concern
White-tailed Lapwing	*Vanellus leucurus* (Lichtenstein 1823)	Charadriidae	Insectivorous	nw	Uncommon	Least concern
Wood Sandpiper	*Tringa glareola* Linnaeus 1758	Scolopacidae	Insectivorous	nw	Common	Least concern
Eurasian Curlew	*Numenius arquata* (Linnaeus 1758)	Scolopacidae	Insectivorous	nw	Uncommon	Least concern
Yellow-wattled Lapwing	*Vanellus malabaricus* (Boddaert 1783)	Charadriidae	Insectivorous	nr	Uncommon	Least concern
Oriental Pratincole	*Glareola maldivarum* J.R. Forster 1795	Glareolidae	Insectivorous	np	Uncommon	Least concern
Greater Painted-Snipe	*Rostratula benghalensis* (Linnaeus 1758)	Rostratulidae	Omnivorous	nw	Common	Least concern
Order: Ciconiiformes						
Asian Openbill-Stork	*Anastomus oscitans* (Boddaert 1783)	Ciconiidae	Carnivorous	nr	Uncommon	Least concern
Painted Stork	*Mycteria leucocephala* (Pennant 1769)	Ciconiidae	Carnivorous	nr	Common	Near threatened
White-necked Stork	*Ciconia episcopus* (Boddaert 1783)	Ciconiidae	Carnivorous	nw	Common	Vulnerable
Order: Columbiformes						
Blue Rock Pigeon	*Columba livia* Gmelin 1789	Columbidae	Granivorous	cr	Very common	Least concern
Eurasian Collared-Dove	*Streptopelia decaocto* (Frivaldszky 1838)	Columbidae	Granivorous	cr	Common	Least concern
Laughing Dove	*Streptopelia senegalensis* (Linnaeus 1766)	Columbidae	Granivorous	cr	Common	Least concern
Red Collared-Dove	*Streptopelia tranquebarica* (Hermann 1804)	Columbidae	Granivorous	cr	Common	Least concern
Spotted Dove	*Streptopelia chinensis* (Scopoli 1786)	Columbidae	Granivorous	cr	Common	Least concern
Yellow-legged Green-Pigeon	*Treron phoenicoptera* (Latham 1790)	Columbidae	Frugivores	cr	Very common	Least concern
Order: Coraciiformes						
Common Kingfisher	*Alcedo atthis* (Linnaeus 1758)	Alcedinidae	Carnivorous	cr	Uncommon	Least concern
Common Hoopoe	*Upupa epops* Linnaeus 1758	Upupidae	Insectivorous	cr	Very common	Least concern
Small Bee-eater	*Merops orientalis* Latham 1801	Meropidae	Insectivorous	cr	Very common	Least concern
Indian Grey Hornbill	*Ocyceros birostris* (Scopoli 1786)	Bucerotidae	Frugivores	cr	Very common	Least concern
Indian Roller	*Coracias benghalensis* (Linnaeus 1758)	Coraciidae	Insectivorous	cr	Common	Least concern
White-breasted Kingfisher	*Halcyon smyrnensis* (Linnaeus 1758)	Alcedinidae	Carnivorous	cr	Very common	Least concern
Stork-billed Kingfisher	*Halcyon capensis* (Linnaeus 1766)	Alcedinidae	Carnivorous	nr	Rare	Least concern
Blue-tailed Bee-eater	*Merops philippinus* Linnaeus 1766	Meropidae	Insectivorous	ns	Uncommon	Least concern

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Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
Order: Cuculiformes						
Asian Koel	*Eudynamys scolopacea* (Linnaeus 1758)	Cuculidae	Omnivorous	ns	Very common	Least concern
Greater Coucal	*Centropus sinensis* (Stephens 1815)	Cuculidae	Insectivorous	cr	Very common	Least concern
Pied Crested Cuckoo	*Clamator jacobinus* (Boddaert 1783)	Cuculidae	Insectivorous	cs	Very common	Least concern
Common Hawk-cuckoo	*Hierococcyx varius* (Vahl 1797)	Cuculidae	Insectivorous	nr	Uncommon	Least concern
Order: Falconiformes						
Peregrine Falcon	*Falco peregrinus* Tunstall 1771	Falconidae	Carnivorous	nr	Rare	Least concern
Order: Galliformes						
Grey Francolin	*Francolinus pondicerianus* (Gmelin 1789)	Phasinidae	Omnivorous	Cr	Very common	Least concern
Indian Peafowl	*Pavo cristatus* Linnaeus 1758	Phasinidae	Omnivorous	Cr	Very common	Least concern
Black Francolin	*Francolinus* (Linnaeus 1766)	Phasianidae	Omnivorous	Cr	Uncommon	Least concern
Order: Gruiformes						
Common Coot	*Fulica atra* Linnaeus 1758	Rallidae	Herbivorous	Cr	Very common	Least concern
Common Moorhen	*Gallinula chloropus* (Linnaeus 1758)	Rallidae	Omnivorous	Cr	Very common	Least concern
Purple Moorhen	*Porphyrio* (Linnaeus 1758)	Rallidae	Omnivorous	Cr	Very common	Least concern
White-Breasted Waterhen	*Amaurornis phoenicurus* (Pennant 1769)	Rallidae	Omnivorous	Cr	Very common	Least concern
Watercock	*Gallicrex cinerea* (Gmelin 1789)	Rallidae	Omnivorous	Ns	Rare	Least concern
Order: Passeriformes						
Long-Tailed Shrike	*Lanius schach* Linnaeus 1758	Laniidae	Carnivorous	Cr	Common	Least concern
Ashy Prinia	*Prinia socialis* Sykes 1832	Cisticolidae	Insectivorous	Cr	Common	Least concern
Asian Pied Starling	*Sturnus contra* Linnaeus 1758	Sturnidae	Omnivorous	Cr	Very common	Least concern
Bank Myna	*Acridotheres ginginianus* (Latham 1790)	Sturnidae	Insectivorous	Cr	Very common	Least concern
Barn Swallow	*Hirundo rustica* Linnaeus 1758	Hirundinidae	Insectivorous	Cw	Very common	Least concern
Baya Weaver	*Ploceus philippinus* (Linnaeus 1766)	Ploceidae	Omnivorous	Cr	Very common	Least concern
Bay-backed Shrike	*Lanius vittatus* Valenciennes 1826	Laniidae	Carnivorous	Cr	Common	Least concern
Bengal Bushlark	*Mirafra assamica* Horsfield 1840	Alaudidae	Omnivorous	Nr	Common	Least concern
Black Drongo	*Dicrurus macrocercus* Vieillot 1817	Dicruridae	Omnivorous	Cr	Very common	Least concern
Black Redstart	*Phoenicurus ochruros* (Gmelin SG 1774)	Muscicapidae	Insectivorous	Cw	Very common	Least concern
Black-headed Bunting	*Emberiza melanocephala* Scopoli 1769	Emberizidae	Granivorous	Np	Common	Least concern
Blue Rock Thrush	*Monticola solitarius* (Linnaeus 1758)	Muscicapidae	Omnivorous	Nr	Rare	Least concern
Bluethroat	*Luscinia svecica* (Linnaeus 1758)	Muscicapidae	Insectivorous	Nw	Common	Least concern
Blyth's Reed Warbler	*Acrocephalus dumetorum* Blyth 1849	Acrocephalidae	Insectivorous	Cp	Uncommon	Least concern
Booted Warbler	*Hippolais caligata* (Lichtenstein 1823)	Acrocephalidae	Insectivorous	Ns	Common	Least concern
Brahminy Myna	*Sturnus pagodarum* (Gmelin 1789)	Sturnidae	Omnivorous	Cr	Very common	Least concern
Brown Rock-Chat	*Cercomela fusca* (Blyth 1851)	Muscicapidae	Insectivorous	Cw	Common	Least concern
Brown Shrike	*Lanius cristatus* Linnaeus 1758	Laniidae	Insectivorous	V	Rare	Least concern
Cinereous Tit	*Parus cinereus* Vieillot 1818	Paridae	Omnivorous	Cp	Rare	Least concern
Citrine Wagtail	*Motacilla citreola* Pallas 1776	Motacillidae	Insectivorous	Cw	Common	Least concern
Common Babbler	*Turdoides caudatus* (Dumont 1823)	Leiothrichidae	Omnivorous	Cr	Common	Least concern
Common Chiffchaff	*Phylloscopus collybita* (Vieillot 1817)	Phylloscopidae	Insectivorous	Cw	Common	Least concern
Common Myna	*Acridotheres tristis* (Linnaeus 1766)	Sturnidae	Omnivorous	Cr	Very common	Least concern

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Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
Greater Whitethroat	*Sylvia communis* (Latham 1787)	Sylviidae	Insectivorous	V	Rare	Least concern
Crested Lark	*Galerida cristata* (Linnaeus 1758)	Alaudidae	Omnivorous	Cr	Common	Least concern
Indian Golden Oriole	*Oriolus kundoo* (Linnaeus 1758)	Oriolidae	Omnivorous	Cs	Common	Least concern
Gray-Throated Martin	*Riparia chinensis* (Gray JE 1830)	Hirundinidae	Insectivorous	Cr	Uncommon	Least concern
Grey Necked Bunting	*Emberiza buchanani* Blyth 1845	Emberizidae	Granivorous	V	Uncommon	Least concern
Grey Wagtail	*Motacilla cinerea* Tunstall 1771	Motacillidae	Insectivorous	Nw	Common	Least concern
House Crow	*Corvus splendens* Vieillot 1817	Corvidae	Omnivorous	Cr	Very common	Least concern
Indian Robin	*Saxicoloides fulicata* (Linnaeus 1776)	Muscicapidae	Insectivorous	Cr	Very common	Least concern
Indian Silverbill	*Lonchura malabarica* (Linnaeus 1758)	Estrildidae	Granivorous	Cr	Very common	Least concern
Jungle Babbler	*Turdoides striatus* (Dumont 1823)	Leiothrichidae	Omnivorous	Cr	Very common	Least concern
Large Grey Babbler	*Turdoides malcolmi* (Sykes 1832)	Leiothrichidae	Omnivorous	Cr	Very common	Least concern
Common Lesser Whitethroat	*Sylvia curruca* (Linnaeus 1758)	Sylviidae	Insectivorous	Nw	Common	Least concern
Oriental Magpie- Robin	*Copsychus saularis* (Linnaeus 1758)	Muscicapidae	Omnivorous	Cr	Very common	Least concern
Indian White Eye	*Zosterops palpebrosa* (Temminck 1824)	Zosteropidae	Omnivorous	Nr	Common	Least concern
Paddyfield Pipit	*Anthus rufulus* Vieillot 1818	Motacillidae	Insectivorous	Cr	Common	Least concern
Pied Bushchat	*Saxicola caprata* (Linnaeus 1766)	Muscicapidae	Insectivorous	Cr	Common	Least concern
Plain Prinia	*Prinia inornata* Sykes 1832	Cisticolidae	Insectivorous	Nr	Very common	Least concern
Purple Sunbird	*Nectarinia asiatica* (Latham 1790)	Nectariniidae	Omnivorous	Cr	Very common	Least concern
Red-Rumped Swallow	*Hirundo daurica* Linnaeus 1771	Hirundinidae	Insectivorous	Nr	Common	Least concern
Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus 1766)	Pycnonotidae	Omnivorous	Cr	Very common	Least concern
Richard's Pipit	*Anthus richardi* Vieillot 1818	Motacillidae	Insectivorous	Np	Common	Least concern
Rock Bunting	*Emberiza cia* Linnaeus 1766	Emberizidae	Granivorous	V	Uncommon	Least concern
Rosy Pipit	*Anthus roseatus* Blyth 1847	Motacillidae	Insectivorous	Nw	Common	Least concern
Indian Tree Pie	*Dendrocitta vagabunda* (Latham 1790)	Corvidae	Omnivorous	Cr	Very common	Least concern
Scaly Thrush	*Zoothera dauma* (Latham 1790)	Turdidae	Insectivorous	Nw	Rare	Least concern
Siberian Chiffchaff	*Phylloscopus tristis* (Blyth 1843)	Phylloscopidae	Insectivorous	Cw	Common	Least concern
Siberian Stonechat	*Saxicola maurus* (Pallas 1773)	Muscicapidae	Insectivorous	Cr	Very common	Least concern
Sind Sparrow	*Passer pyrrhonotus* Blyth 1844	Passeridae	Granivorous	Lcr	Uncommon	Least concern
Scaly- breasted Munia	*Lonchura punctulata* (Linnaeus 1758)	Estrildidae	Omnivorous	Cr	Very common	Least concern
Zitting Cisticola	*Cisticola juncidis* (Rafinesque 1810)	Cisticolidae	Insectivorous	Cr	Very common	Least concern
Sykes's Warbler	*Iduna rama* (Sykes 1832)	Acrocephalidae	Insectivorous	Cr	Common	Least concern
Tailor Bird	*Orthotomus sutorius* (Pennant 1769)	Cisticolidae	Omnivorous	Cr	Very common	Least concern
EurasianTree Pipit	*Anthus trivialis* (Linnaeus 1758)	Motacillidae	Omnivorous	Nw	Very common	Least concern
Verditer Flycatcher	*Eumyias thalassina* (Swainson 1838)	Muscicapidae	Insectivorous	Nw	Rare	Least concern
Western Yellow Headed Wagtail	*Motacilla flava* Linnaeus 1758	Motacillidae	Insectivorous	Cw	Common	Least concern
White Tailed Stonechat	*Saxicola leucurus* (Blyth 1847)	Muscicapidae	Insectivorous	Lcr	Common	Least concern
White Wagtail	*Motacilla alba* Linnaeus 1758	Motacillidae	Insectivorous	Cw	Common	Least concern
Wire-Tailed Swallow	*Hirundo smithii* Leach 1818	Hirundinidae	Insectivorous	Cs	Common	Least concern
Yellow Eyed Babbler	*Chrysomma sinense* (Gmelin 1789)	Paradoxornithidae	Omnivorous	Cr	Uncommon	Least concern
Streaked Weaver	*Ploceus manyar* (Horsfield 1821)	Ploceidae	Insectivorous	Cr	Uncommon	Least concern
Asian Paradise-Flycatcher	*Terpsiphone paradisi* (Linnaeus 1758)	Monarchidae	Insectivorous	Ns	Rare	Least concern

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Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
European Starling	*Sturnus vulgaris* Linnaeus 1758	Sturnidae	Insectivorous	Cr	Very common	Least concern
Grey Headed CanaryFlycatcher	*Culicicapa ceylonensis* (Swainson 1820)	Stenostiridae	Insectivorous	Nw	Rare	Least concern
Common Woodshrike	*Tephrodornis pondicerianus* (Gmelin 1789)	Vangidae	Insectivorous	Cr	Uncommon	Least concern
House Sparrow	*Passer domesticus* (Linnaeus 1758)	Passeridae	Granivorous	Cr	Uncommon	Least concern
Jungle Myna	*Acridotheres fuscus* (Wagler 1827)	Sturnidae	Insectivorous	Cr	Rare	Least concern
Blue Whistling Thrush	*Myophonus caeruleus* (Scopoli 1786)	Muscicapidae	Insectivorous	Nw	Rare	Least concern
Indian Pitta	*Pitta brachyura* (Linnaeus 1766)	Pittidae	Insectivorous	Ns	Rare	Least concern
Red-Headed Bunting	*Emberiza bruniceps* Brandt 1841	Emberizidae	Granivorous	Np	Rare	Least concern
Red Avadavat	*Amandava amandava* (Linnaeus 1758)	Estrildidae	Granivorous	Nr	Uncommon	Least concern
Streak Throated Swallow	*Hirundo fluvicola* Blyth 1855	Hirundinidae	Insectivorous	Nr	Common	Least concern
Indian Bushlark	*Mirafra erythroptera* Blyth 1845	Alaudidae	Insectivorous	Cr	Common	Least concern
Rufous-fronted Prinia	*Prinia buchanani* Blyth 1844	Cisticolidae	Insectivorous	Cr	Uncommon	Least concern
Gray-breasted Prinia	*Prinia hodgsonii* Blyth 1844	Cisticolidae	Insectivorous	Nr	Uncommon	Least concern
Long-billed Pipit	*Anthus similis Jerdon* 1840	Motacillidae	Insectivorous	Nw	Common	Least concern
Hume's Warbler	*Phylloscopus humei* (Brooks 1878)	Phylloscopidae	Insectivorous	Nw	Common	Least concern
Red- breasted Flycatcher	*Ficedula parva* (Bechstein 1792)	Muscicapidae	Frugivores	Nw	Uncommon	Least concern
Black Breasted weaver	*Ploceus benghalensis* (Linnaeus 1758)	Ploceidae	Granivorous	Cr	Uncommon	Least concern
Graceful Prinia	*Prinia gracilis* (Lichtenstein 1823)	Cisticolidae	Insectivorous	Nr	Common	Least concern
Asian brown flycatcher	*Muscicapa dauurica* Pallas 1811	Muscicapidae	Insectivorous	Nw	Uncommon	Least concern
Variable wheatear	*Oenanthe picata* (Blyth 1847)	Muscicapidae	Insectivorous	Cw	Common	Least concern
Greenish Leaf-Warbler	*Phylloscopus trochiloides* (Sundevall 1837)	Phylloscopidae	Insectivorous	Cp	Uncommon	Least concern
Oriental Tree Pipit	*Anthus hodgsoni* Richmond 1907	Motacillidae	Insectivorous	Cw	Common	Least concern
Great Tit	*Parus major Linnaeus* 1758	Paridae	Insectivorous	Cw	Common	Least concern
Eurasian Skylark	*Alauda arvensis* Linnaeus 1758	Alaudidae	Insectivorous	Nw	Common	Least concern
Desert Wheatear	Oenanthe deserti*(Temminck 1825)*	Muscicapidae	Insectivorous	Nw	Uncommon	Least concern
White-eared Bulbul	*Pycnonotus leucotis* (Gould 1836)	Pycnonotidae	Insectivorous	Nr	Uncommon	Least concern
Black-headed Oriole	*Oriolus xanthornus*(Linnaeus 1758)	Oriolidae	Omnivorous	Nr	Common	Least concern
Order: Pelecaniformes						
Black Headed White Ibis	*Threskiornis melanocephalus* (Latham 1790)	Threskiornithidae	Carnivorous	Nr	Common	Near threatened
Cattle Egret	*Bubulcus ibis* (Linnaeus 1758)	Ardeidae	Carnivorous	Cr	Very common	Least concern
Eurasian Spoonbill	*Platalea leucorodia* Linnaeus 1758	Threskiornithidae	Carnivorous	Nr	Rare	Least concern
Grey Heron	*Ardea cinerea* Linnaeus 1758	Ardeidae	Carnivorous	Cr	Uncommon	Least concern
Indian Pond Heron	*Ardeola grayii* (Sykes 1832)	Ardeidae	Carnivorous	Cr	Very common	Least concern
Intermediate Egret	*Egretta intermedia* Wagler 1829	Ardeidae	Carnivorous	Cr	Very common	Least concern
Great Egret	*Egretta alba* Linnaeus 1758	Ardeidae	Carnivorous	Cr	Uncommon	Least concern
Little Egret	*Egretta garzetta* (Linnaeus 1766)	Ardeidae	Carnivorous	Cr	Very common	Least concern
Night Heron	*Nycticorax nycticorax* (Linnaeus 1758)	Ardeidae	Carnivorous	Cr	Very common	Least concern
Purple Heron	*Ardea purpurea* Linnaeus 1766	Ardeidae	Carnivorous	Nr	Common	Least concern

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Table 1. Birds with their feeding habits, distribution, occurrence and IUCN status

Name	Scientific name	Family	Feeding habits	Status	Occurrence	IUCN
Red- Naped Ibis	*Pseudibis papillosa* (Temminck 1824)	Threskiornithidae	Carnivorous	Nr	Very common	Least concern
Yellow Bittern	*Ixobrychus sinensis* (Gmelin 1789)	Ardeidae	Carnivorous	Ns	Rare	Least concern
Cinnamon Bittern	*Ixobrychus cinnamomeus* (Gmelin 1789)	Ardeidae	Carnivorous	Ns	Rare	Least concern
Striated Heron	*Butorides striata* (Linnaeus 1758)	Ardeidae	Carnivorous	Nr	Rare	Least concern
Order: Piciformes						
Brown Headed Barbet	*Megalaima zeylanica* (Gmelin 1788)	Megalaimidae	Frugivores	Cr	Common	Least concern
Coppersmith Barbet	*Megalaima haemacephala* (P.L.S. Müller 1776)	Megalaimidae	Frugivores	Cr	Common	Least concern
Lesser Goldenbacked Woodpecker	*Dinopium benghalense* (Linnaeus 1758)	Picidae	Omnivorous	Cr	Common	Least concern
Yellow Crowned Woodpecker	*Leiopicus mahrattensis* (Latham 1801)	Picidae	Insectivorous	Cr	Rare	Least concern
Order: Podicipediformes						
Little Grebe	*Tachybaptus ruficollis* (Pallas 1764)	Podicipedidae	Carnivorous	Cr	Very common	Least concern
Order: Psittaciformes						
Alexandrine Parakeet	*Psittacula eupatria* (Linnaeus 1766)	Psittaculidae	Frugivores	Cr	Common	Near threatened
Plum Headed Parakeet	*Psittacula cyanocephala* (Linnaeus 1766)	Psittaculidae	Frugivores	Cr	Uncommon	Least concern
Rose Ringed Parakeet	*Psittacula krameri* (Scopoli 1769)	Psittaculidae	Frugivores	Cr	Very common	Least concern
Order: Strigiformes						
Barn Owl	*Tyto alba* (Scopoli 1769)	Tytonidae	Carnivorous	Cr	Uncommon	Least concern
Indian Scops Owl	*Otus bakkamoena* Pennant 1769	Strigidae	Carnivorous	Nr	Common	Least concern
Spotted Owlet	*Athene brama* (Temminck 1821)	Strigidae	Carnivorous	Cr	Very common	Least concern
Order: suliformes						
Great Cormorant	*Phalacrocorax carbo* (Linnaeus 1758)	Phalacrocoracidae	Carnivorous	Cr	Uncommon	Least concern
Little Cormorant	*Phalacrocorax niger* (Vieillot 1817)	Phalacrocoracidae	Carnivorous	Cr	Common	Least concern
Oriental Darter	*Anhinga melanogaster* Pennant 1769	Anhingidae	Carnivorous	Lcr	Rare	Near threatened

Common resident (cr), common passage migrant (cp), common summer visitor (cs), common winter visitor (cw),locally common resident (lcr), locally common winter visitor (lcw), not common passage migrant (np), not common resident (nr), not common summer visitor (ns),not common winter visitor (nw), not common winter visitor and passage migrant (nwp), vagrant (v)

species. It is believed that moderate level of urban development shows higher species diversity and abundance, moreover species diversity decreases with urban development but at the same time abundance of urban dwelling birds increases Sengupta et al (2014). Most of the species unused or partially used land for residence shows more species diversity. The species which shows multiple broods per year such as pigeons increased with urban development as this phenomenon offers maximum nesting and foraging to these birds (Blair 2004).

CONCLUSION

Total of 204 bird species belonging to 18 orders and 58 families were recorded. Most of the birds found during survey were listed under Least Concern category of Red List of IUCN, but few of them were listed under vulnerable, near threatened and endangered categories. The maintaining more woodlands and green areas with more heterogeneity is the only way to conserve the avian biodiversity. Similarly, most of the earlier workers have suggested the importance of green spaces with structural diversity in vegetation, which help to develop various resources to bird diversity and other wildlife animals. It is a major responsibility of the state government, Municipal Corporation and state agencies to develop the habitats with native species of plants and maintain structural diversity that can help to restore the biodiversity.

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First Record of Sea Urchin *Temnopleurus toreumaticus* (Leske 1778) (Echinoidea: Temnopleuridae) from Estuaries of West Coast of India

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***Abstract*:** Sea urchins are spiny marine benthic organisms under the phylum Echinodermata. Being marine organisms, the larvae are often transported to estuaries by waves and settle on finding a suitable location to mark their presence in estuaries. The present paper deals with the first record of sea urchin *Temnopleurus toreumaticus* from two estuaries along the West coast of India along with its possible implications. Specimens were collected from the upper stretch of Valappattanam (16km from the estuarine mouth) and Dharmadam (7km from the estuarine mouth) estuaries with the salinity ranging from 23 to 35 ppt. The intrusion of saline waters through tidal flux is the major factor for the migration of sea urchins towards the upstream of the estuary. Further studies regarding the settlement and proliferation of sea urchins in estuaries are required to delineate the possible management strategies.

***Keywords*:** Sea urchin, *Temnopleurus toreumaticus,* Estuaries, Salinity intrusion, South West coast India

Sea urchins belong to the class Echinoid which shows pentaradial symmetry and moves using hundreds of tiny tube feet (Raghunathan et al 2012). A total of 138 species of echinoids were reported from all over India (Samuel et al 2017) including sea urchins. Most of them are marine, being intertidal inhabiting chiefly on coral reefs, sandy beaches, muddy flats, and rocky coasts but rarely found in estuaries also. Studies on echinoderms from the Indian estuaries were very few in number and most are from the east coast. The notable works include Naveen Kumar and Raghunathan (2018) from Hoogly-Matlah and Godavari estuary, Mitra et al (2010) from the Subarnarekha estuary, Mahapatro et al (2011) from the Brahmani-Baitarani, Sastry (2008) from Krishna estuary and Kankal and Warudkar (2012) from the Pennar estuary. Indian estuaries represent 3.60 and 0.37% of the total echinoderm species reported in India and the world respectively (Naveen Kumar and Raghunathan 2018). Out of 28 species reported from Indian estuaries under the phylum Echinodermata, only 6 species (*Chaetodiadema granulatum, Temnopleurus toreumaticus, Echinus sp. Clypeaster rarispinus, Laganum decagonale* and *Sculpsitechinus auritus*) belongs to the class Echinoidea. *Temnopleurus toreumaticus* commonly known as striped spine sea urchin is commonly distributed along the coastal waters of India (Usha 2016). It has also been reported from three estuaries along the east coast of India viz., Hoogly Matlah and Godavari estuary(Naveen Kumar and Raghunathan 2018) and Subarnarekha estuary (Mithra et al 2010). This paper records the first-ever report on the unusual incidence of *Temnopleurus toreumaticus* in the upper reaches of two tropical estuaries along the southwest coast of India. The probable causes for the occurrence of this species in the upper estuary and its implications on local fisheries were also discussed.

MATERIAL AND METHODS

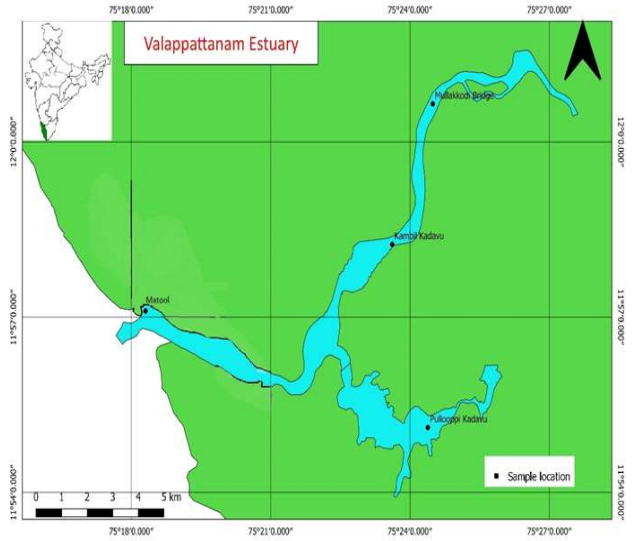
Study area: The incidence of sea urchins was observed during pre-monsoon months (March to May 2022) from the Valappattanam (VAL) (Lat 11°94'99" N, 75°30'14" E) and the Dharmadam estuary (DHA) (Lat 11°48'28"N, 75°27'35"E (Fig. 1a-b) of the Kannur district, North Kerala. The study was conducted in a regular exploratory survey as part of the doctoral research project. The occurrence of sea urchins was observed from 6 sampling locations in VAL and DHA estuary (four from the VAL estuary: Matool, Pulloppi Kadavu, Kambil Kadavu, and Mullakodi Bridge and two from the DHA estuary - Dharmadam Bridge and Parapram Bridge).

Sample collection: The samples were collected through the fishing operations conducted in the region. Major crafts used were plank-built canoes and dug-out canoes which two fishermen can accommodate. Sea urchins were generally caught as bycatch from bottom set gillnets of 18-150 mm mesh size, 70-200m length, which is soaked 4 hours per day, and shore seine 12-26 mm mesh size, length 24-58m which is operated 3-4 hours per day. Salinity was measured from each station by the refractometer (ERMA Japan) with an accuracy of ±0.001 and the reading was measured in ppt. The collected samples were brought to the lab for further detailed morphological and anatomical observation. Taxonomic identification was carried out following the keys of Hedge and Rivonker (2013). By interacting with the local fisherman, information on various implications of the incidence of sea urchins in the estuary was collected.

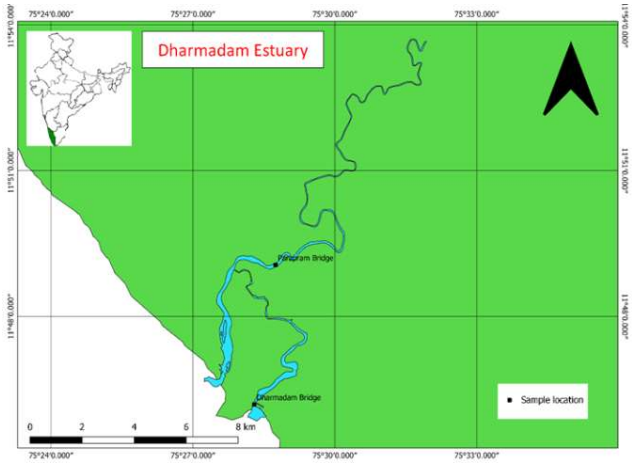
RESULTS AND DISCUSSION

An unusual incidence of sea urchin *Temnopleurus toreumaticus* (Fig. 2 a-b) was observed at the upper stretch of VAL estuary (16 km from the estuarine mouth) and DHA estuary (7 km from the estuarine

mouth) during the pre-monsoon season (March-May 2022). The organisms were encountered in the bottom set gill net (100-150 mm mesh size, 70-200m length) and shore seine (12-26 mm mesh size and length 24-58m) operated for 3-4 hrs. The salinity near the estuarine mouth region (Matool and Dharmadam Bridge) was 30-35ppt and depth 3-5m. Whereas the salinity and depth vary between 23-27ppt and 3-6m at the upper stretches (Pullooppi Kadavu, Kambil Kadavu Mullakkodi bridge, and Parapram bridge) of both VAL and DHA estuaries. The occurrence of this marine species in the upper stretch of the estuary can be attributed to the intrusion of coastal waters into the estuaries during the Pre-monsoon season. The main factors affecting salinity intrusion in the VAL River are the topography (due to unsystematic dredging), the sea level variation, an increase in temperature, and decrease in precipitation (Arunraj and Vasudeo 2015).



a. Valapattanam estuary



b. Dharmadam estuary

Fig. 1. Location of *Temnopleurus toreumaticus* observed in Valapattanam and Dharmadam estuaries

Temnopleurus torumaticus is widely distributed among, Singapore, Madagascar, East Africa the Persian Gulf, the Red Sea, Japan, and on the east coast of Australia (Kroh et al 2011, Sastry 2012, Jeffrey 2015, Sonet et al 2022). Earlier reports from Indian coastal waters show that this species is widely distributed and inhabits sandy and muddy substrata between 5-40 m in depth (Sastry 2012, Usha 2016) (Table 1).

Species Classification and Description

Class: Echinoidea Leske 1778
Subclass: Euechinoidea Bronn 1860
Superorder: Camarodonta Jackson 1912
Order: Temnopleuroida Mortensen 1942
Infraorder: Temnopleuridea Kroh & Smith 2010
Family: Temnopleuridae A. Agassiz 1872
Genus: *Temnopleurus*
Species: *Torumaticus*

Long-spined urchin, with a diameter of about 3-5 cm and height of 1.5-2.5 cm. Primary spines are long, equal to half of the horizontal test diameter, banded with reddish or brown colour bands, and pore-pairs arranged in arcs. The test is Dome-shaped, well sculptured with

a

b

Fig. 2. a. Oral-aboral view of the specimen. b. Discarded by catch species *Temnopleurus toreumaticus* on shore at Matool station (near bar mouth) of Valapattanam estuary

Table 1. Ecological attributes of *Temnopleurus toreumaticus* globally, in other Indian estuaries, and in the present study

Attributes	Global range	Other Indian East Coast Estuaries	Present study
Species	*Temnopleurus toreumaticus*	*Temnopleurus toreumaticus*	*Temnopleurus toreumaticus*
Salinity	20-35ppt	30-35ppt	23-35 ppt
Temp	10-30°c	Not available	29-30.5°c
pH	7.5-8.5	Not available	7.5-8.5
Depth	0-79m	Not available	0-6m
Habitat	Rocky shore, estuaries, sandy and muddy bottoms.	Mostly at Barmouth. Inhabits sandy, muddy, and rocky bottoms	Estuary, rocky, sandy, and muddy bottoms.
References	Nateghi et al 2016	Hoogly-matlah estuary, Godavari estuary (Naveen Kumar and Raghunathan 2018) Subarnarekha estuary (Mithra et al 2010)	Valapattanam and Dharmadam estuary.

a convex aboral surface. The test comprises five pairs of alternately placed ambulacral and interambulacral plates placed at about the level of the ambulacral plates. Ambulacral plates are compound trigeminate, their pore-pairs bearing numerous tube feet (in living specimens). The test Color is Olive green to dark grey. It is covered with soft skin and comprises five pairs of buccal plates. Periproct is roughly circular.

The landings of Sea urchins as bycatch occurs more during the summer season (Dinesh 2015, Hegde and Rivonker 2013). Sea urchin spawning and proliferation may be enhanced by higher water temperatures during summer months along with the reduced predator's abundance (such as fish) caused by intensive fishing (Hereu et al 2012). A significant amount of sea urchin in India is landed by commercial fisheries as bycatch (Saravanan et al 2018). In the present study *Temnopleurus toreumaticus* are mostly caught as bycatch from shore seine (marine) and bottom set gill nets (estuary). The peak spawning period of this particular species was found during December (Saravan et al 2017). The larvae of *Temonopleurus toreumaticus* metamorphosis into juveniles 30 days after fertilization (Kitazawa et al 2014). Chemical cues from rocky areas and the turbulent environment help sea urchin larvae to drift and find a suitable environment for settling (Gaylord et al 2013). Both VAL and DHA estuaries have hard substratum which may also be a favourable factor for the mass settlement of sea urchins in the regions. Based on the opinions of fishermen, sea urchins are been caught as bycatch in recent years making it difficult for them to sort fish from the nets once get entangled. An average of 10-15 sea urchins get caught in each net during this particular proliferation period (pre-monsoon time). Sea urchins may seem harmless due to their sedentary nature but have the potency to sting humans using their long venomous spines when stepped on them accidentally. Stings cause severe pain and swell when the edge of the spine is broken and left inside the skin. A rinsing with methylated spirit and hot water may help in providing relief from the pain and immobilize the affected area of the body (James et al 2010).

Sea urchins demonstrate physiological and dietary flexibility, whereby individuals can make metabolic and behavioral adjustments, or switch to alternative foods (e.g., drift algae, turfing algae, invertebrates, detritus) when preferred food is scarce (Ling and Johnson 2009, Suskiewicz and Johnson 2017). *Temnopleurus toreumatics* mostly feeds on green seaweed *Caulerapa peltate* and *C.serulata* and seagrasses *Cymodocea serrulata* and *Syringodium isoetifolium* (Saravanan 2022). Even though most overgrazing events seem to affect areas of <0.5km^{2}it can cause long-term effects such as decreased sediment stabilization, reduction of algal beds and associated fauna. This can eventually alter the food web structure if left unnoticed. Factors influencing overgrazing include bottom-up (nutrient enrichment), top-down (reduced predation control due to e.g., overfishing), "side-in" mechanisms (e.g., changes in water temperature), and natural population fluctuations (Eklof et al 2008).

CONCLUSION

The present communication deals with the incidence of long-spined sea urchin *Temnopleurus toreumaticus* (Leske 1778) from the upper stretches of VAL and DHA estuaries of Kerala along the southwest coast of India during pre-monsoon months. The salinity intrusion during the pre-monsoon period is the major factor for the migration of sea urchins towards the upstream of the estuary. Fisherfolks find very difficult to remove once they are caught on the net accidentally. Despite the numerous ecological role sea urchin provides to the ecosystem; excess settlement causes reduction in algal beds which indirectly affects the fishes which depend on them. This can even result in an ecological shift if overlooked. The study recommends strong monitoring system during the occurrence of this seasonal occurrence.

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AUTHORS CONTRIBUTION

Swetha KC: Sample collection, analysis, conceptualisation, and manuscript preparation, Jayalakshmi KJ: Overall supervision, conceptualisation, and review, Usha Parameswaran: Identification of Sample , Sreekanth GB: Review and editing.

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Biodiversity and Conservation Status of Fish Fauna in Lake Fateh Sagar Udaipur, Rajasthan (India)

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***Abstract*:** The present study deals with the diversity and abundance of fresh water fishes in Fateh Sagar lake of Udaipur district, Rajasthan during 2017-18. The results of present investigation reveal the occurrence of 28 fish species belonging to 10 families and 19 genera. Among the collected species, family Cyprinidae was most dominant constituting 46.42% followed by family Bagridae and Channidae constituting 10.71% each, family Balitoridae and Siluridae constituting 7.14% each, family Notopteridae, Saccobranchidae, Centropomidae, Belonidae and Mastacembelidae were represented by 3.57% each of the total fish species. The fish diversity was 3.20659 by using Shannon-Weaver diversity index. The conservation status of these fishes was assessed according to IUCN criteria. The major threats faced by the freshwater fishes are mostly in the form of human interventions and aquatic pollution.

Keywords: Fish diversity, Fateh Sagar lake, Shannon-Weaver diversity index, IUCN status

Indian fresh water fish fauna is highly diverse. Extensive literature on freshwater fishes in India is available but mostly concerned with taxonomy (Hamilton 1822, Day 1875 Talwar and Jhingran 1991, Menon 1992 and Jayaram 1999). Ichthyofauna of different states of India have been described by various researchers (Bhat and Rao 2018, Sharma 2018 , Sharma and Dhanze 2018, Prasad et al 2020, Rawat et al 2020,Thakur et al 2021, Walter Devaa and Ramesh 2021). The state of Rajasthan has great potentialities for the growth of Inland fisheries. There are a large number of rivers, streams, lakes, tanks and seasonal ponds. However, very little is known about the fish fauna of Rajasthan. But the important work has been done by Sharma and Chaudhary (2007), Gaur (2011), Banyal and Kumar (2015) and Gaur and Nagar (2021). Globally, aquatic ecosystems are among the most threatened ecosystems, suffering from declines in biodiversity that are far greater than those in even the most severely affected terrestrial ecosystems (Dudgeon et al 2006). The major threats to the aquatic resources are overexploitation, introduction of exotic species, habitat degradation and anthropogenic activities. The present investigation was under taken to study the fish biodiversity, abundance of fishes and their IUCN status of Fateh Sagar lake.

MATERIAL AND METHODS

Study area: Lake Fateh Sagar is situated in Udaipur city at Latitude 24°36'07"N, Longitude 73°40'31"E and Altitude 587 m, msl. It is an artificial lake, constructed to the north-west of Udaipur and located to the north of Lake Pichhola (Fig. 1). The runoff emerging from surrounding hills drains into this lake. The lake is pear-shaped and is encircled by the Aravalli hills on three sides with a straight gravity stone masonry dam on the eastern side which has a spillway to discharge flood flows during the monsoon season (Fig. 2).

Collection of fish sample: The fishes were collected from different points of the lake during Oct-2017 to Sep-2018 with the help of local government contractor and some illegal fishermen using different types of nets namely gillnets, casts nets and dragnets. The collected fishes were photographed labeled and preserved in 10% formalin solution and brought to the laboratory for the identification (Day 1878, Talwar and Jhingran 1991, Jayaram 1999). Fish diversity was calculated by using Shannon-Weaver diversity index. (Shannon - Weaver 1949).

$$H' = - \Sigma Pi \ln Pi$$

Where, H' = Shannon Weaver index, Pi = ni/N = the number of individuals of a species (ni) divided by the total number of individuals, (N) present in the entire sample and ln = Natural log

The conservation status of fish species was based on the criteria given by CAMP (1998) and IUCN (2015).

RESULTS AND DISCUSSION

During present study total 28 ichthyospecies with abundance of 78 have been recorded belonging to 19 genera and 10 families. The members of family Cyprinidae were represented by 13 species (53%), followed by Channidae

and Bagridae with three species each(10%), Balitoridae and Siluridae was expressed by two species each(6%), Notopteridae, Saccobranchidae, Centropomidae, Belonidae and Mastacembelidae were represented by one species only(3%) (Fig. 3). The Shannon- Weavers diversity index of the lake Fateh Sagar was 3.20659. Datta and Majumdar (1970) recorded 75 fish species belonging to 36 genera and 16 families from Rajasthan, as per records of Zoological Survey of India. Johal et al (1993) reported 95 fish species belonging to 52 genera, 7 orders and 5 super orders. Gaur

Fig. 1. Lake Fateh Sagar in winter season

Fig. 2. Lake Fateh Sagar in rainy season

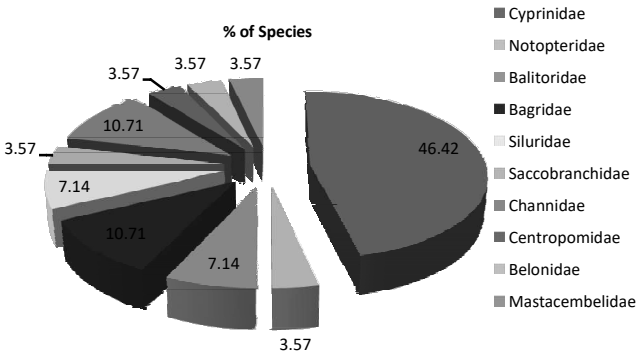

Fig. 3. Family-wise percentage composition of fish fauna of Lake Fateh Sagar

Fig. 4. Selected fish species of Lake Fateh Sagar

(2011) recorded 30 species belonging to 20 genera and 8 families from some tributaries of river Chambal of South-eastern Rajasthan. According to the IUCN, among all the 28 species recorded in Fateh Sagar lake, 4 fish species are Lower risk near threatened (LR-nt) viz. *Cirrhinus mrigala, Labeo bata, Labeo calbasu and Mastacembelus armatus* ,8 species are Vulnerable (VU) viz. *Systomus sarana, Labeo gonius, Mystus cavasius, Wallago attu, Callichrous pabda, Heteropneustes fossilis, Channa marulius and Xenentodon cancila* and 15 species of fish are Lower risk least concern(LR-lc) (Table 1). According to the present study, lake Fateh Sagar supports a vast diversity of fish fauna (Fig. 4). Efforts for conservation are necessary for the IUCN categorized 28 fish species of the study area.

CONCLUSION

Present investigation was aimed at diversity and status of fresh water fishes in Fateh Sagar lake of Udaipur district, Rajasthan. Based on Shannon-Weaver diversity index the

Table 1. Ichthyofauna of lake Fateh sagar in Udaipur district of Rajasthan

Species	Local name	Max. size observed	Status	Economic value
Family – Cyprinidae				
Chela bacaila (Ham.)	Chilwa	16 cm	LRlc	LV
Rasbora daniconius (Ham.)	Zebra	18 cm	LRlc	LV
Puntius ticto (Ham.)	Putti	12 cm	LRlc	BT, LV, WF
Systomus sarana (Ham.)	Putti	22 cm	VU	BT, LV, WF
Puntius sophore (Ham.)	Putti	10 cm	LRlc	BT, LV, WF
Amblypharyngodon mola (Ham.)	Mola	14cm	LRlc	LV
Catla (Ham.)	Catla	25 cm	LRlc	FD
Cirrhinus mrigala (Ham.)	Mrigal	22cm	LRnt	FD
Labeo rohita (Ham.)	*Rohu*	24 cm	LRlc	FD
Labeo bata (Ham.)	Bata	18 cm	LRnt	FD
Labeo boggut (Sykes)	Dudhiya	16 cm	LRlc	FD
Labeo gonius (Ham.)	Sarsi	15 cm	VU	FD
Labeo calbasu ((Ham.)	Kalaunt	17 cm	LRnt	FD
Family – Notopteridae				
Notopterus (Pallas)	Patola	22 cm	EN	PF, FD
Family – Balitoridae				
Noemacheilus botia (Ham.)	Bamna	10 cm	LRlc	MD
Noemacheilus danisonii (Ham.)	Bamna	7.5 cm	LRlc	MD
Family- Bagridae				
Sperata seenghala (Sykes)	Singhara	32 cm	LRlc	PF, FD
Mystus cavasius (Sykes)	Katava	18 cm	VU	PF, FD
Mystus oar (Ham.)	-	19 cm	LRlc	PF, FD
Family – Siluridae				
Wallago attu (Bloch)	Lachi	32 cm	VU	PF, FD
Callichrous pabda	Pabda	18 cm	VU	FD
Family-Saccobranchidae				
Heteropneustes fossilis	Singhi	11cm	VU	FD
Family – Channidae				
Channa punctatus (Bloch)	Girhi	12 cm	LRlc	LV, FD
Channa marulius (Ham.)	Saval	10 cm	VU	LV, FD
Channa striatus (Bloch)	Kabra	8 cm	LRlc	LV, FD
Family – Centropomidae				
Chanda nama (Ham.)	Sisa	11cm	LRlc	LV, PF
Family – Belonidae				
Xenentodon cancila (Ham.)	Suhia	28 cm	VU	WF
Family – *Mastacembelidae*				
Mastacembelus armatus	Bam	40 cm	LRnt	PF

Status : LR-nt -Lower risk near threatened, VU-Vulnerable, LR-lc -Lower risk least concern and EN-Endangered.
Economic Value: LV – Larvivorous fish, BT- Bait, PF- Predatory Food Fish, WF- Weed Fish, MD- Medicinal Value, FD- Food Fish

moderate fish diversity was found in Fateh Sagar lake which is due to aquatic pollution. The economic importance of fishes revealed that the most of the fish species are food fishes and have medicinal valve also hence the conservation measures should be taken. According to IUCN categorized 28 fish species of the study area many species are vulnerable and near threatened so efforts should be made for conservation of these species.

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Crustaceans Diversity along Mangroves of Sikka Coast, Gulf of Kachchh, Gujarat, India

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***Abstract*:** The present study was conducted at two identical sites of the Sikka coast namely DCC (Digvijay Cement Company) jetty area and the GSFC (Gujarat State Fertilizer and Chemicals Limited) jetty area from October 2020 to March 2021. The observations were recorded at monthly intervals for the abundance of crustacean species. In total 13 crustacean species were identified of 13 genera and 11 families, including 9 brachyuran crabs, 2 shrimps, 1 porcelain crab and 1 barnacle. Nine genera, eight families, and nine species of brachyuran crabs were recorded. Shrimps encountered with two families, two genera, and two species. Presence of *Avicenna marina,* a common mangrove, is a good sign as it provides sites of attachment to the barnacle (*Amphibalanus Amphitrite*). The GSFC jetty area recorded the highest number of species during December and lowest was in October. In DCC area, the highest number of species were in March and the fewest number in October. *Metapograpsus thukuhar* and *Austruca iranica* (Uca crab) were the most common species of family Grapsidae and Ocypodidae, respectively.

***Keywords*:** Mangrove, Crustaceans, Brachyuran crabs, Porcelain crab, Sikka coast, Jetty

The Gulf of Kachchh is veritably rich in floral and faunal diversity and comprises different types of communities and habitats with very unique coral reefs, mangroves, sandy shores, rocky shores and mudflats (Trivedi et al 2012). The mangroves are one of the most productive ecosystems distributed along the tropical coast and act as a buffer zone between the land and the ocean (Jatav et al 2022). The mangroves are salt-tolerant plants that arise within the intertidal zone of the tropical and subtropical estuarine regions (Morrisey et al 2010) and are very important to the ecosystem as they protect the coast from erosion and provide many resources for utilization in the forestry, fisheries, food, agriculture and pharmaceutical industries (Venkatesan et al 2010). As mangroves act as a nursery, a high juvenile abundance of many aquatic organisms is seen in mangrove forest as they get shelter, feed and protection (Murugan and Anandhi 2016). The global crustacean species diversity is estimated to be 1, 50,000 of which 40,000 species have been described, and among these, 2808 species of crustacean have been reported from the Indian coastal and marine habitats (Chandra et al 2016, Tandel et al 2022). From an ecological point of view, crabs are the most important faunal communities in the marine ecosystem (Raval 2020). They are filter feeders, sand cleaners, mud, plant, carrion feeders, predators, commensalism and parasites. They feed on various marine animals such as squid, fish, turtles, and mammals (Josileen 2011). The coastal areas provide place for breeding, nesting, foraging and shelter for economically important organisms (Dev Roy and Sivaperuman 2012). Hence, most of the growing population in the world lives within easy reach of coastal areas. Lobsters, crabs, crayfish, shrimps, barnacles, *etc*. are very important in the food web as well as nutrient recycling and are most crucial in the human economy (Varada et al 2016). Apart from the food web, crustaceans are also an important unique source of nutrients like proteins, fats and minerals to aquatic life as well as to human beings (Nagelkerken et al 2008). The chitin and chitosan extracted from the crustaceans are used for medicines and chemical applications. The skeletons are used as food for livestock and poultries (Giri et al 2011). Crustaceans are one of the ecologically important faunal communities in the marine ecosystem. The crabs and shrimps play a significant role in detritus formation, recycling of nutrients and overall dynamics of ecosystems (Beleem et al 2014). Crustaceans had modified their body structures to fulfill their requirements of capturing food, habitat modification, camouflage with background and mechanism of offense and defense (Ponnada 2019). Crustaceans are a

good source of vitamins, minerals, protein, copper and phosphorus. In the mangrove ecosystem, the burrowing activity of crabs increases the porosity of the soil, which also increases the regeneration of mangrove seedlings (Khan et al 2005). Considering the importance of mangrove ecosystem as crucial component of crustacean diversity, the present study is carried out to identify the key aspects of the growth of crustaceans around the mangroves and relation of crustaceans with mangroves.

MATERIAL AND METHODS

Study area: The present study was carried out at two locations (site I (Digvijay Cement Company jetty area) and site II (Gujarat State Fertilizer and Chemicals Limited jetty area)) along the Sikka coast (situated at 22° 49′ 17.7″N latitude and 69° 20′ 33.8″E longitude) in the Gulf of Kachchh, India. Sikka coast is. The study confined for mangrove crustaceans and was carried from October 2020 to March 2021.

Sampling methods: Crustacean diversity was recorded at the selected two sites at different locations in the upper and lower levels of the mangrove swamp (Fig. 1, 2). The ebb tide durations were selected for the survey. Voucher specimens were collected for photographic and morphometric studies. The burrowing animals were dug out and caught with the help of forceps. The collected specimens were stored in plastic jars with labels and preserved in 70% ethyl alcohol. Samples were sorted and identified to the species level or to the closest taxa in the laboratory (Fisheries Research Station, JAU, Sikka). A variety of sources of information were used for identification, including the Marine Species Identification Portal website (www.speciesidentification.org), the FAO species identification guide for fishery purposes, the Manual on Taxonomy, and the identification of commercially important Indian crustaceans based on morphometric and meristic traits.

RESULTS AND DISCUSSION

In total of 13 species of crustaceans were recorded during the study which belong to 11 families and 13 genera. The recorded faunal assemblage includes 9 brachyuran crabs, 2 shrimps, 1 porcelain crab and 1 barnacle species. Brachyuran crabs recorded belong to seven families, nine genera and nine species were recorded (Table 1). The mangrove plant *Avicenna marina* acts as a host for barnacle *Amphibalanus amphitrite*. The trunk as well as roots acts as attachment surface. The barnacles are act as a fauling organism and might impede gas exchange ability of mangrove. The GSFC jetty area recorded the highest number of species of crustacean during December, and lowest in October. At the DCC area, the highest number of species were seen in March and lowest in October. During the study period, *Metapograpsus thukuhar* and *Austruca irania* (Uca crab) were the most common species belonging to the family grapsidae and ocypodidae, respectively. The species composition showed that 77% of the species belonged to crabs, 15% shrimp and the rest 8% were barnacles (Figure 3). The diversity and comparison of the two sites showed that 48% of the species occurred DCC jetty area while 52% in the GSFC jetty area (Figure 4). Families such as grapsidae and portunidae contains 2 species while families like pilumnidae, oziidae, sesarmidae, macrophthalmidae, ocypodidae and porcellanidae contains single species during study (Fig. 5). Shrimps belonged to families Alpheidae (1 species) and Penaeidae (1 species) and barnacles to family balanidae (1 species). List of crustaceans recorded along mangroves of Sikka coast, Gulf of Kachchh, Gujarat, India (Table 1).

Brachyuran crabs and other benthic animals like shrimp and fish can thrive exceptionally in mangroves. But compared to open mudflat habitats, the diversity was lower. Sesarmidae, grapsidae, and ocypodidae were only a few of the families that make up the majority of the brachyuran crab diversity found in mangroves. Ten species of brachyuran

Fig. 1. Map of Gujarat, Gulf of Kachchh

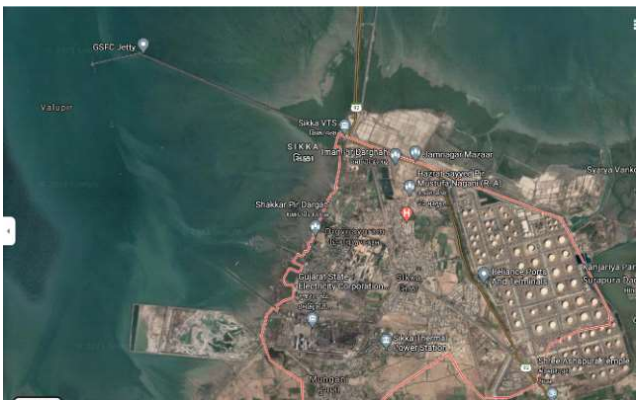

Fig. 2. Map of Sikka coast

Table 1. Check list of crustaceans along mangrove of Sikka coast, Gulf of Kachchh, Gujarat, India

Species	DCC jetty area	GSFC jetty area
Grapsidae		
Metapograpsus thukuhar (Macleay 1838)	+	+
Thalamita crenata (Ruppell 1830)	+	+
Portanidae		
Scylla serrata (Forskal 1775)	+	+
Eurycarcinus orientalis (A. Milne-Edwards 1867)	+	+
Pilumnidae		
Heteropanope glabra (Stimpson 1858)	+	+
Oziidae		
Epixanthus frontalis (H. Milne Edwaeds 1834)	+	+
Sesarmidae		
Parasesarma persicum (Naderloo & Schubart 2010)	+	+
Macrophthalmidae		
Macropthalamus depressus (Ruppell 1830)	+	+
Ocypodidae		
Austruca irania (Pretzmann 1971)	+	+
Porcellanidae		
Petrolisthes rufescens (Heller 1861)	+	-
Alpheidae		
Alpheus inopinatus (Holthuis and Gottlieb 1958)	-	+
Penaeidae		
Fenneropenaeus indicus (H. Milne-Edwards 1837)	-	+
Balanidae		
Amphibalanus amphitrite (Darwin 1854)	+	+

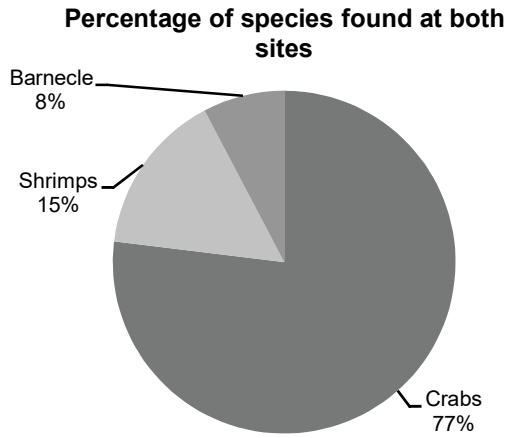

Fig. 3. Percentage of species of different groups found at both sites

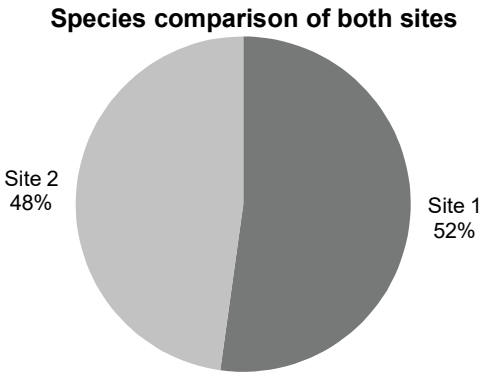

Fig. 4. Species comparison at both sites

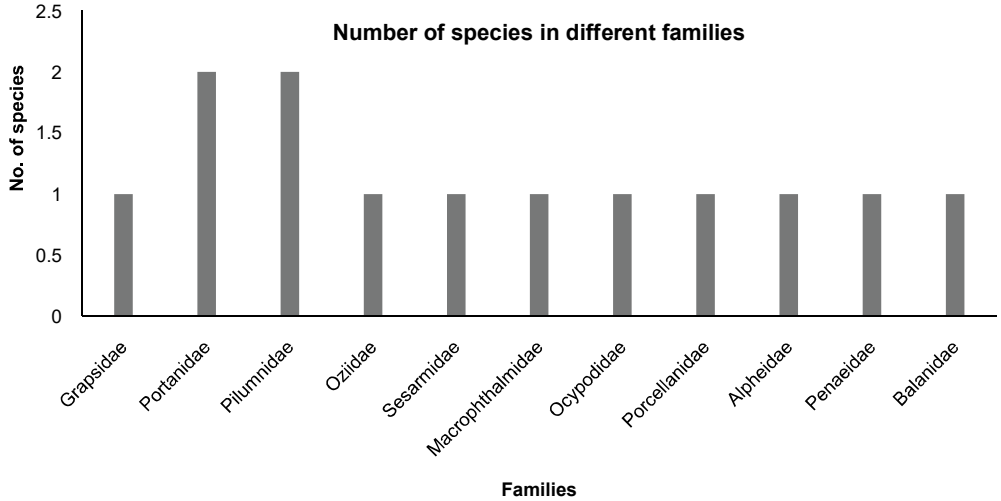

Fig. 5. Graph showing the number of species in different families


Metapograpsus thukuhar


Thalamita crenata


Epixanthus frontalis


Scylla serrata


Eurycarcinus orientalis


Parasesarma persicum


Macropthalamus depressus


Heteropanope glabra


Austruca iranica


Fenneropenaeus indicus


Alpheus inopinatus


Amphibalanus Amphitrite

Table 2. Species of crustaceans collected from mangrove of Sikka coast, Gulf of Kachchh, Gujarat

crabs have been recorded in mangrove mudflats by Trivedi et al (2012). Mangrove mud flats were dominated by the families grapsidae and portunidae, each of which contributed three species. From every site surveyed, *U. lactea annlipes* and *P. plictum* were recorded. Nine brachyuran crab species belonging to seven families were recorded in the current study. In the Pichavaram mangroves, Khan et al (2005) recorded 38 species of brachyuran crabs, of which 18 species belonged to the family grapsidae and 8 to the family ocypodidae. Grapsidae and ocypodidae are the two dominant families in the current study too.

CONCLUSION

Crustacean play very crucial rolet of mangrove ecosystem as they make holes which facilitate aeration in deep mud and many aerobic bacteria as well as other fauna can be settle. Mangroves are recognized as an essential part of coastal ecosystems because of their high production and ability to support a range of animal species. Crustaceans are important for the preservation of mangrove ecosystems because they help to preserve nutrients for the growth of mangrove trees. A wide variety of crustaceans can observed in the diversified and dispersed mangrove ecosystem along the Sikka coast. The diversity and comparison showed that 48% of the species were reported in the Digvijay Cement Company area while 52% were in the Gujarat State Fertilizer and Chemical limited jetty area. *Metapograpsus thukuhar* and *Austruca irania* (Uca crab) were the most common

species belonging to the family grapsidae and ocypodidae, respectively. In Sikka, mangrove areas are growing more and more intensely as a result of silt deposition in a few locations, but they are under severe stress in other locations due to anthropogenic activities like pollution and the allocation of the intertidal zone for industrial purposes like shipbuilding and repairs. Species wise both location have showing difference and species composition is also differ this might be due to difference in the mangrove density and mangrove height. Gsfc jetty site have very dence mangrove canopy compare to DCC jetty and gsfc jetty area is comparatively less polluted compared to other area. This research will help identify the crustacean diversity of mangrove areas along the Sikka coast of Gujarat. This research will also help us to identify the key aspects of the growth of crustaceans around the mangroves or the relation of crustaceans with mangroves.

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Development of Chironji Nut (*Buchanania lanzan*) Grader-cum-Decorticator

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***Abstract*:** PDKV Chironji nut Grader cum Decorticator (CNGD) machine consists of grading hopper, decortication hopper, sieve assembly, outlets, and motor.The performance evaluation for Grading unit was optimized with 39 experiments. The performance evaluation for Decortication unit were optimized with 29 experiments. The experiments were generated through Box-Behnken Design and the experimental data was analyzed by applying Response Surface Methodology (RSM) using Design Expert 12.0.8.0 software for optimising the input parameters. The optimized input parameters of700 rpm oscillating speed of sieve assembly, 180 kg/h feed rate and three sieves each of diameter 9 ,7 and 5mm showed the grading efficiency of 98.81%. The optimized input parameters of8% wb moisture content of nut, 80kg/h feed rate, 750 rpm speed of disc and 8 mm clearance between pair of stone disc showed the decortication efficiency of 76.87%.The developed chironji nut grader cum decorticator would help the cooperative farmers, tribal people, small help groups and unemployed youths for becoming an entrepreneur.

***Keywords*:** Chironji, Decorticator, Grader, Value addition, Whole kernel, Capacity, Efficiency

Buchanania lanzan (chironji) belongs to family Anacardiaceae and is commercially very useful. Chironji originated in the Indian sub-continent and is found growing naturally as wild stands in the tropical deciduous forests of north, western and central India mostly in the states of Madhya Pradesh, Bihar, Orissa, Andhra Pradesh, Chhattisgarh, Jharkhand, Gujarat, Karnataka, Varanasi, Rajasthan, Maharashtra and Uttar Pradesh. Chironji kernels have great medicinal values. The whole kernel is used in sweets, meats, expectorant and tonic. Chironji kernels contain 52% oil which is used for treating skin diseases and considered as a substitute for almond oil in traditional medicine preparations. Kernel is rich in nutrients and an active source of crude protein, crude fat, carbohydrates, crude fiber and other rich nutrients like phenolics, natural antioxidants, fatty acids and minerals (Kumar et al 2009). In manual chironji nut decortication process, there is very less recovery of whole kernel and remaining is nearly broken or mashed. There is excessive loss due to crude methodology adopted, which leads not only to huge economical loss but also loss of nutrition (Kumar et al 2009). Traditional processing method of chironji is very cumbersome, time consuming and labour extensive and becomes difficult to get labour for this operation. Thus, in order to get good recovery of chironji kernels, the processing costbecomes higher (Singh et al 2016). The presence of hard seed coat is one of the problem in decortications of nuts. The variation in the dimension of chironji nut also affects the whole kernel recovery. The improper decortications prove to damage the kernel during storage and spoil the kernel. Thus, reduction in shelf life of chironji kernel is observed giving low economic value (Dwived et al 2012).Therefore, the present study was carried out with two objectives development of chironjinut grader cum decorticator and performance evaluation of chironjinut grader cum decorticator.

MATERIAL AND METHODS

The chironji nuts were procured from local farmers of Patur Tehsil of Akola district and Gadchiroli district. PDKV chironji nut grader cum decorticator machine was developed consist of grading hopper, decortication hopper, sieve assembly, outlets, and motor (Plate 1). The optimized experimental design and performance evaluation of grading unit (39 experiments) (Table 1) and decortication unit (29 experiments) (Table 2) of chironjinut grader cum decorticatorwere generated through Box-Behnken Design and the experimental data was analyzed by applying Response Surface Methodology (RSM) using Design Expert 12.0.8.0 software.

A. Experimental Design and Performance evaluation of Grading Unit (Table 1& 2):

The type of oscillating speed of sieve assembly, feed rate and sieve sets (different combinations) were optimized for maximum grading efficiency of chironji nuts

Independent variables:

a. Oscillating speed of sieve assembly, rpm (600, 650, 700, 750 and 800)

b. Feed rate (F), kg/h60, 120, 180, 240 and 300

c. Sieve sets (different combinations)

First sieve set- (Three round hole sieves - dia. as – 9 mm (T), 7mm (M) & 5mm (B)

Second sieve set- Three round hole sieves- dia. as – 8 mm (T), 7mm (M) & 5mm (B)

Third sieve set - Three round hole sieves – dia. as – 8 mm (T), 6mm (M) & 5mm (B)

Dependent variables:

a. Grading Efficiency

The extraction efficiency was calculated using the following formula.

Grading efficiency, % = 100 – un-graded nuts

$$\text{Un – graded nuts (\%)} = \frac{\text{Weight of un – graded nuts, g}}{\text{Weight of total nuts input, g}}$$

Plate 1. Chironji nut grader cum decorticator

Table 1. Levels of independent variables for chironji nut decortication

Independent variables	Symbols		Levels			
	Coded	Un-coded	Coded			Un-coded
Moisture content (% wb) of chironji nut	x_1	M	1	0	-1	9, 8, 7
Feed rate (kg/h)	x_3	F	1	0	-1	100, 80, 60
Speed of Disc (rpm)	x_2	S	1	0	-1	800, 750, 700
Clearance between pair of discs, mm	x_4	C	1	0	-1	10, 8, 6

Table 2. Effect of independent parameters on grading efficiency of chironji nut

Source	Sum of squares	df	Mean Square	F-value	p-value	
Model	418.89	6	69.81	48.91	< 0.0001	Significant
A- Oscillating speed of sieve assembly, rpm	0.3573	1	0.3573	0.2503	0.6203	
B- Feed rate, kg/h	1.67	1	1.67	1.17	0.2851	
C- Sieve sets (Different combinations)	228.20	2	119.75	83.90	< 0.0001	
A^2	50.96	1	50.96	35.71	< 0.0001	
B^2	141.31	1	141.31	99.00	< 0.0001	
Residual	45.67	32	1.43			
Lack of Fit	41.30	19	1.64	1.47	0.2394	Not significant
Pure Error	14.47	13	1.11			
Cor Total	337.56	38				
Std. Dev.	1.19					
Mean	94.55					
C.V. %	1.24					
R^2	0.9268					
Adjusted R^2	0.8963					
Predicted R^2	0.8612					
Adeq Precision	11.0773					

B. Experimental Design and Performance evaluation of Decortication Unit (Table 3 & 4):

Response-surface methodology comprises of methods used for exploring the optimum operating conditions through experimental methods. The levels of independent variables for chironji nut decorticator unit are given in table 3.

Dependent variables:

1. Coefficient of hulling/decortications (E_h)

The coefficient of hulling/decortications was calculated by using the formula given by Sahay and Singh (2002) and Kachru et al (1919).

$$E_h = 100(1-\frac{n2}{n1})$$

where,

n_1 = weight of unhulled nuts before decortication

n_2 = weight of unhulled nuts after decortication

1. Coefficient of wholeness of kernel (Ewk):

The coefficient of wholeness of kernel was determined by using the formula computed by Sahay and Singh (2002) and Kachru et al (1991).

$$E_{wk} = \left(\frac{(k2-k1)}{(k2-k1)+(d2-d1)+(m2-m1)}\right)$$

where,

k_1, k_2 = weight of whole kernels before and after decortication

d_1, d_2 = weight of broken kernels before and after decortication

m_1, m_2 = weight of mealy waste before and after decortication

3. Decortication efficiency η (%):

The coefficient of wholeness of kernel was determined by using the formula computed by Sahay and Singh (2002), Kachru et al (1991).

$$\eta\ (\%) = E_h \times E_w$$

RESULTS AND DISCUSSION

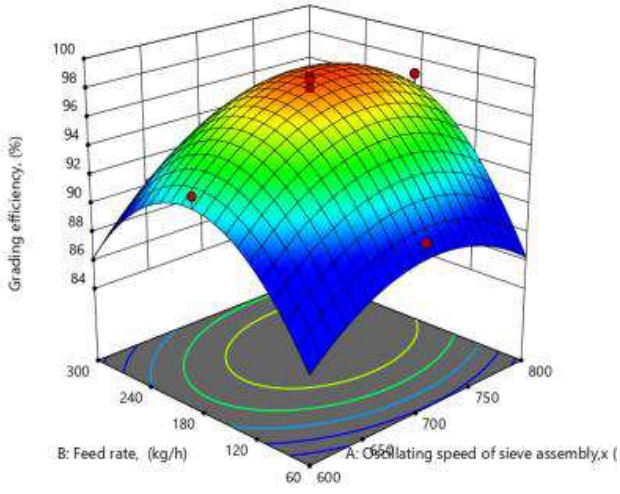
The experimental trials were conducted to optimize the input parameters and evaluated the performance. The maximum and minimum grading efficiency was observed to be 98.81 and 87.02%. For grading efficiency, the model F-value of 48.91 implies that the model was significant. The linear terms oscillating speed of sieve assembly, feed rate and different sieve sets were found to be significant. The lack of fit F-value was which indicates that the developed model is adequate for predicting the response. Moreover, the predicted R^2 of 0.8612 was in reasonable agreement with adjusted R^2 of 0.8963. This revealed that the non-significant terms have not been included in the model. Therefore, this model could be used to navigate the design space. High value of coefficient of determination (R^2 = 0.9268) obtained for response variable indicated that the developed model for grading efficiency accounted for and adequately explained 92.68 % of the total variation.

The feed rate increased, the grading efficiency increased up to certain level and as the feed rate increased beyond significant level, the grading efficiency was decreased in all sieve sets. This might be due to excess raw material above certain limit created hindrance for rubbing action between sieves and the nuts. This resulted in less grading at higher feed rates.

The experimental trials were conducted to optimize the input parameters and evaluated the performance. The maximum and minimum decortication efficiency was observed to be 77.19% and 51.84% Response Surface Methodology (RSM) was applied to the experimental data using the package, Design- Expert version 12 (Statease Inc, Minneapol was, USA, Trial version, 2018).

The Model F-value 16.50 implies that the model was significant Table 4. There was only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms were significant. In this case A, B, C, D, A^2, B^2, C^2, D^2 were significant model terms. Values greater than 0.1000 indicate the model terms were not significant. The Lack of Fit F-value of 5.08 implies there was 6.56% chance that a Lack of Fit F-value this large occurred due to noise. Non-significant lack of fit was good and thus, the model was fit for obtaining the response.

The R^2 value was computed by a least square technique and 0.9429 showing good fit of model to the data. The



The optimized input parameters for grading efficiency of chironji nut were found to be:

1) Oscillating speed of sieve assembly, rpm = 701.518 ~ 700
2) Feed rate (kg/h) = 176.891~ 180
3) Type of sieve set = first sieve set [three round hole sieves with diameter as – 9 mm (T), 7mm (M) and 5mm(B)]

Fig. 1. Effect of oscillating speed of sieve assembly and feed rate on grading efficiency of chironji nut (first sieve set)

Predicted R^2 of 0.6883 was in reasonable agreement with the Adjusted R^2 of 0.8857 i.e. the difference was less than 0.2. Adeq. Precision measures the signal to noise ratio. A ratio greater than 4 was desirable. Ratio of 12.893 indicated an adequate signal. So this model was used to navigate the design space (Table 5 & Fig. 3)

The feed rate of 80 kg/h was sufficient for getting maximum decortication efficiency as feed rate allowed the free flowing of nut for decortication without any type of clogging in hopper and pair of disc. It was observed that, at the speed of disc 750 rpm and 8 mm clearance between pair of disc were best combination for getting maximum decortication efficiency. Experiments reveled that, as the speed was decreased then, more undecorticated nuts were obtained and when the speed was increased then more brokens were obtained. Thus, the process and machine parameters *viz*. moisture content 8 % wb, feed rate 80 kg/h, speed of disc 750 rpm and clearance between pair of disc 8 mm were the best combination of variables for getting maximum decortication efficiency.

Table 3. Analysis of variance (ANOVA) showing the effect of process and machine parameters on decortication efficiency

Source	Sum of squares	df	Mean square	F-value	p-value	
Model	1695.81	14	121.13	16.50	< 0.0001	Significant
A-Moisture Content	261.80	1	261.80	35.66	< 0.0001	
B-Feed Rate	48.84	1	48.84	6.65	0.0218	
C-Speed of Disc	65.10	1	65.10	8.87	0.0100	
D-Pair of Disc	73.56	1	73.56	10.02	0.0069	
AB	0.7569	1	0.7569	0.1031	0.7529	
AC	0.0506	1	0.0506	0.0069	0.9350	
AD	12.11	1	12.11	1.65	0.2199	
BC	0.0036	1	0.0036	0.0005	0.9826	
BD	6.43	1	6.43	0.8753	0.3653	
CD	11.63	1	11.63	1.58	0.2288	
A^2	157.09	1	157.09	21.40	0.0004	
B^2	509.33	1	509.33	69.38	< 0.0001	
C^2	264.55	1	264.55	36.03	< 0.0001	
D^2	830.64	1	830.64	113.14	< 0.0001	
Residual	102.78	14	7.34			
Lack of Fit	95.28	10	9.53	5.08	0.0656	Non significant
Pure Error	7.50	4	1.88			
Cor Total	1798.59	28				
Std. Dev.	2.71		R^2	0.9429		
Mean	63.16		Adjusted R^2	0.8857		
C.V. %	4.29		Predicted R^2	0.6883		
			Adeq.Precision	12.8929		

Table 4. Optimization criteria for different process variables and responses for chironji nut decortication

Name	Goal	Lower limit	Upper limit
Moisture content (% wb)	is in range	7	9
Feed rate (kg/h)	is in range	60	100
Speed of disc (rpm)	is in range	700	800
Clearance between pair of disc (mm)	is in range	6	10
Coefficient of decortication	Maximum	79	94
Coefficient of wholeness of kernel	Maximum	0.61	0.83
Decortication efficiency (%)	Maximum	51.84	77.19

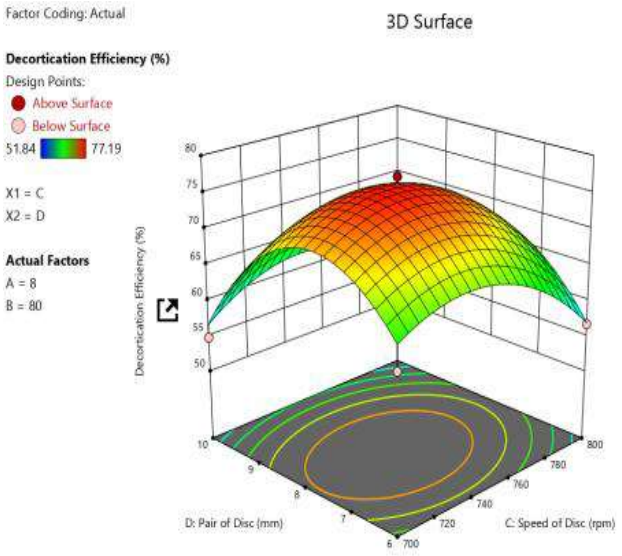


Fig. 3. Effect of SOD and POD on decortication efficiency at MR=8% (wb) and FR=80Kg/h

Optimization of different process input variables for chironji nut decortications: A stationary point at which the slope of the response surface was zero in all the direction was calculated by partially differentiating the model with respect to each variable, equating these derivatives to zero and simultaneously solving the resulting equations, thus simultaneously optimizing the multiple responses. The desired goals for each factor and responses were chosen in Table 6.

CONCLUSIONS

The developed PDKV Chironji nut Grader cum Decorticator has a grading efficiency of 98.81 and decortication efficiency 76.87 per cent.

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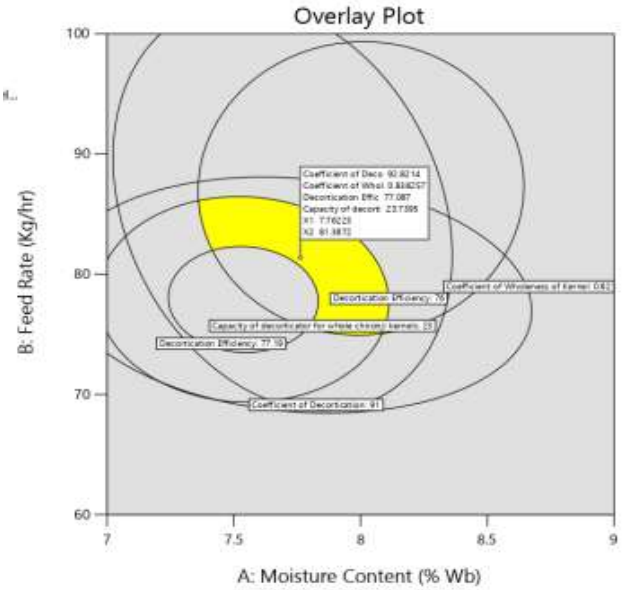

The optimum values of operational variables obtained by numerical optimization (Fig. 5)
Moisture content, % wb = 7.65 ~ 8
Feed rate, kg/h = 83.46 ~ 80
Speed of disc, rpm = 734.60 ~ 750
Clearance between pair of disc, mm = 7.92 ~ 8

Fig. 4. Effect of moisture content (MR) and feed rate (FR) on various responses

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Development of Biodegradable Film from Chitosan and Lemongrass Essential Oil for Food Packaging Applications

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***Abstract*:** Biodegradable films developed from chitosan and lemongrass essential oil to reduce the use of synthetic polymers in food industry. A biopolymer chitosan was dissolved in acetic acid to form chitosan solution and lemongrass essential oil was added to that solution to improve antimicrobial properties of film. This solution was casted and dried in polypropylene petri dish and polypropylene sheet and the dried film was peeled off. Solution was prepared in different quantities (50, 70, 100, 130, 150, and 200 ml) and dried on same sized (27cm×19 cm) sheets in order to obtain required thickness of the film. An attempt was made to fabricate films with combination of chitosan and glycerol. Coloured films also developed by adding edible colours into film forming solution. Highest value of thickness was observed for, 100 ml solution in 176 cm^2 petri dish and for 300 ml solution on 513 cm^2 polypropylene sheets as 0.05 mm. L*a*b values in determination of colour of films were reasonably less indicating its transparency. Highest values of mechanical strength obtained as peak load of 73.25 N and deformation at peak load of 12.45 mm for tensile force and average peak load of 20.153 N for puncture force, was for 150 ml solution casted in 513 cm^2 polypropylene sheet whose thickness is 0.03 mm. Films formed from chitosan and lemongrass essential oil were degraded in 4 months.

***Keywords*:** Chitosan, Lemongrass essential oil, Biodegradable film, Antimicrobial

Synthetic plastic films used in food packaging industries causing severe environmental hazards. To encounter this problem, bio-based degradable films are growing importance these days. Chitin is a biopolymer found in the exoskeletons of crustaceans (shrimps, oysters, krill, crabs, squid, and lobsters) (Priyadarshi and Rhim 2020). Chitosan is obtained by N-deacetylation of chitin in an alkaline environment (Sahib-ul-Islam et al 2017). It is a copolymer made up of β-(1-4)-2-acetamido-D-glucose and β-(1-4)-2-amino-D-glucose (Mollah et al 2016). Chitosan is a nontoxic polymer consisting of antibacterial (Jiwook et al 2018),antifungal, anti-allergenic, antimicrobial, and anti-tumor properties and due to its properties, such as selective gas permeability (only for CO2 and O2), good mechanical properties, biocompatibility, and biodegradability, is environmental friendly and is considered a good film-forming material (Chaudhary et al 2020). Chitosan has limitation on application caused by low solubility in water and thus acetic acid acts as a solvent to dissolve the chitosan.

Lemongrass essential oil extracted from lemongrass, which belongs to *Poaceae* Family (Aashima et al 2020). It exhibits Antibacterial, antifungal, antiprotozoal, anti-inflammatory, antioxidant, anti-tussive, antiseptic, anti-carcinogenic, cardio protective and anti-rheumatic properties (Naik et al 2010) and thus, addition of lemongrass essential oil helps in increasing shelf life of food products packed in these biodegradable films (Riquelme et al 2017). Glycerol is a colourless, odourless, viscous liquid that is sweet-tasting and non-toxic and have high hydrogen bond ability that leads to a good interaction with chitosan macro molecules (Maria et al 2016). Addition of glycerol made bioplastic films flexible (higher elongation at break) (Hidayati et al 2021) and easier to degrade under wet and dry soil.Artificial edible food colours or natural colours extracted from food materials like vegetables, fruits, flowers, can be used in the biodegradable films (Mollah et al 2016). These colours provide pleasing appearance and help in degrading process. This project was undertaken to develop a biodegradable film from chitosan and lemongrass essential oil to reduce the use of synthetic polymers in food industry in order to reduce environmental hazards causing by synthetic plastics.

MATERIAL AND METHODS

Chitosan-from shrimp shells 75% (deacetylated) purchased from Elegance Scientifics, Dattasai Commercial complex, RTC X Road, Hyderabad, Telangana, 500020. Lemongrass oil purchased through authorized online marketing app from R V Essential, India. Acetic acid and glycerol procured from Saphire Scientific Co. 5-4-147, Ranigunj, M.G. Road, Secunderabad, 500003. Polypropylene petri dish and polypropylene sheets were used for casting of films.

Preparation of biodegradable films from chitosan and lemongrass essential oil: By using solvent casting method, biodegradable film was developed by forming the chitosan solution. Chitosan powder was added in the diluted acetic acid (Marina et al 2019) in certain ratio (1% w/w CH_3COOH). The solution was heated at 50°C and stirred (500rpm) on hot plate magnetic stirrer until complete dissolution of chitosan in acetic acid. Then double filtration process was carried out with the help of muslin cloth. Lemongrass essential oil (Ludmila et al 2021) was added in filtered solution to get film forming solution and it was heated and stirred at 50 °C for 10 to 15 min. Coloring agents were added in some samples at this stage and again filtered to form a clear solution. Casting of the filtered solution was carried out on a petri dish or polypropylene sheet. It was dried under electrically operated blower for 24hours. Experiment was carried out in room temperature varied from 26°C to 28°C.

Chitosan solution was prepared in different compositions by dissolving chitosan in diluted acetic acid (1% w/w) and film forming solution was obtained by mixing of lemongrass essential oil (Table 1) and an attempt was made to cast solution on different types of moulds like, glass petri dish, polypropylene petri dish, iron metal dish and polypropylene sheet. Best films were formed on polypropylene petri dish and polypropylene sheets. Troubles encountered while peeling the film from glass petri dish and iron metal dish. Polypropylene petri dish and polypropylene sheet of 176 cm^2 and 513 cm^2 size respectively were used for casting of films. Film forming solution was also formed by combination of glycerol, coconut oil, lime yellow food colour and natural colouring agents like beetroot juice with chitosan solution (Table 2). Films with lemongrass essential oil were found as best due to its good physical and mechanical properties.

Physical and Mechanical Properties Analysis

Thickness of the film (mm): Thickness of the film was measured by using thickness gauge (Make: Mitutoyo, No.2046S, made in Japan). Thickness values taken at 5 random locations on each film and average value considered.

Colour of the film: The colour characterization was carried out using Spectrophotometer Hunter Lab (Make: ColorFlex EZ) colorimeter with the CIELAB system represented by: L (luminosity 0 to 100), chromaticity a* (-a green, +a red) and chromaticity b* (-b blue, +b yellow) (Santhosh et al 2018). Three readings were taken for each film and average value considered.

Tensile test: The mechanical properties were determined by tensile tests (tensile strength and elasticity) using a Texture Analyzer (BROOKFIELD, MODEL: CT3 50K). (Antonio et al 2020). The specimen used was 25 mm wide and 90 mm long, the space between the claws was adjusted to 60 mm, the velocity was 0.5 mm/s. Probe: TA-DGA and Fixture: TA-DGA

Table 1. Different composition of biodegradable films

Sample	Distilled water (ml)	Acetic acid (ml)	Chitosan (g)	Lemongrass oil (ml)	Mould used for casting
S1	100	1	1	0.05	Polypropylene petri dish
S2	70	0.7	0.7	0.035	Polypropylene sheet
S3	50	0.5	0.5	0.025	Polypropylene sheet
S4	130	1.3	1.3	0.065	Polypropylene sheet
S5	150	1.5	1.5	0.075	Polypropylene sheet
S6	300	3	3	0.15	Polypropylene sheet
S7	75	0.75	0.75	0	Polypropylene sheet

Table 2. Different compositions involved in biodegradable films

	Sample-S8	Sample-S9	Sample-S10	Sample-S11
Distilled water (ml)	100	100	75	200
Acetic acid (ml)	1	1	0.75	2
Chitosan (g)	1	1	0.75	2
Lemongrass oil(ml)	0.05	0.05	0	0.1
Glycerol (ml)	0.05	0	0	0
Lime yellow food colour (g)	0	0.1	0	0
Coconut oil (ml)	0	0	0.037	0
Beetroot juice (ml)	0	0	0	1.3
Mould used for casting	Polypropylene sheet	Polypropylene sheet	Polypropylene sheet	Polypropylene petri dish

were used to determine tensile strength of the film (Landova et al 2014).

Puncture test: The puncture force was determined using Texture Analyzer. The films were fixed to two acrylic plates with a small opening at its centre. Probe**:** TA39 and Fixture**:** TA-JPA were used to determine puncture force (Landova et al 2014).

Biodegradability of film: Biodegradability was tested in soil (Haiquan et al 2019). Biodegradable film was placed in soil and checked at 10 days interval.

RESULTS AND DISCUSSION

Thickness (mm): The highest thickness obtained for S1, S6, S11, with compositions of 100, 300, and 200 ml respectively. S1 sample casted on polypropylene petri dish (176 cm^2) S6 sample casted on polypropylene sheet (513 cm^2) and S11 sample with beetroot juice addition casted on polypropylene sheet (513 cm^2). Thickness of sample increased with the amount of solution poured on polypropylene sheet.

Colour: The L*a*b values of films were reasonably less, indicating all the films were almost transparent. Sample S9 in which lime yellow food colour was added having 100 ml composition, clearly shows yellow colour as the b value is +9.26. Sample S11 in which beetroot juice was added having 200 ml composition, showing slightly higher b value of +1.43, but the colour of this S11 sample is not homogenous and not durable as it lasted for only 1 week.

Tensile test: Highest values of peak load at tensile force and deformation at peak load observed for Sample S5 with 150 ml composition ad 0.03 mm thickness as 73.256 N and 12.45 mm respectively. Peak load at tensile force for samples S6, S1, S9 with 300, 100, and 100 ml compositions respectively were also found good and the values as, 65.21, 51.583, and 50.72 N respectively and for the same samples, deformation at peak load were observed as, 10.14, 2.93, and 2.82 mm respectively.

Puncture test: Highest values of puncture force observed for samples S5, S9 (lime yellow colored), S1, S6 with

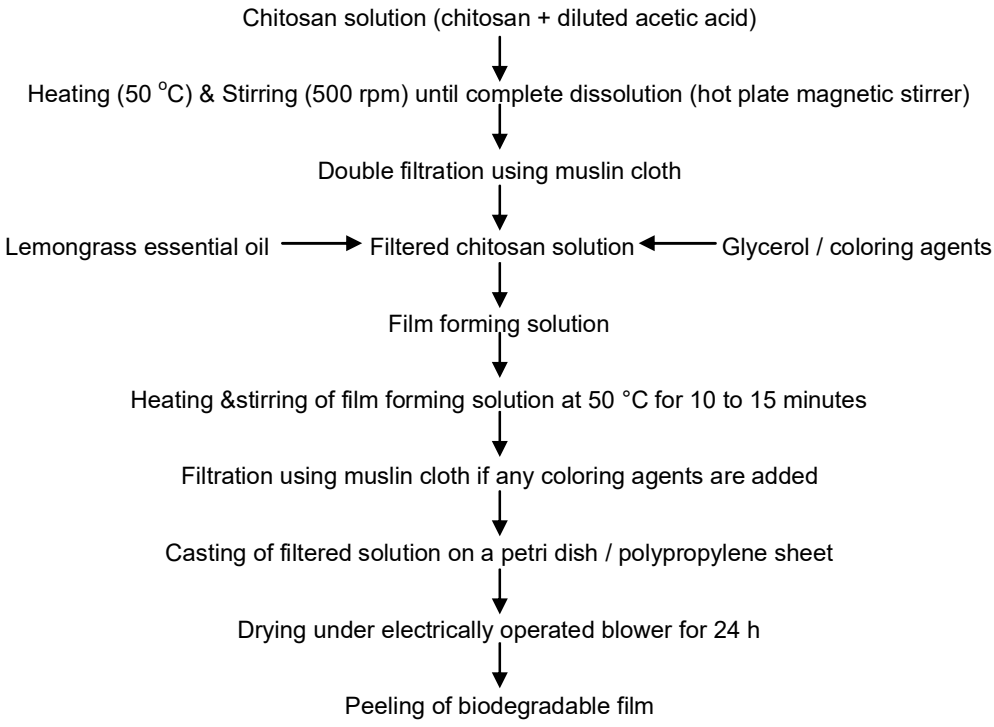

Fig. 1. Flow chart for development of biodegradable film with chitosan and lemongrass essential oil

compositions 150, 100, 100, and 300 ml as 20.153, 19.564, 16.818, and 16.230 N respectively. Puncture force indicating the ability of the film to resist against punctures.

The above graphs representing the tensile strength and stress-strain curves during puncture test for biodegradable films for samples S5 and S6. The deformation of film and rupture at peak load, Sample S5 shows highest peak load and deformation indicating, best tensile strength and deformation properties (Fig. 3, 4). The peak load at which film ruptured during puncture force, Sample S5 shows highest peak load, hence it can withstand more puncture force compared to other samples (Fig. 5, 6).

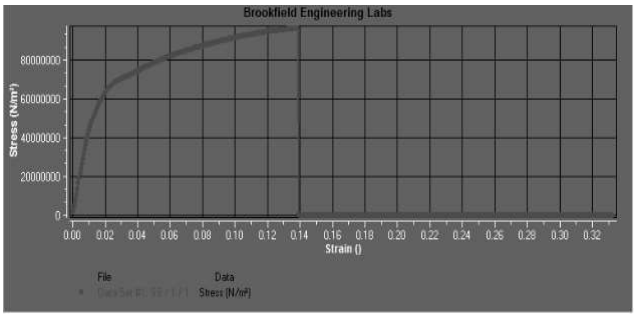

Fig. 2. Variation of tensile stress with respect to tensile strain for sample 5

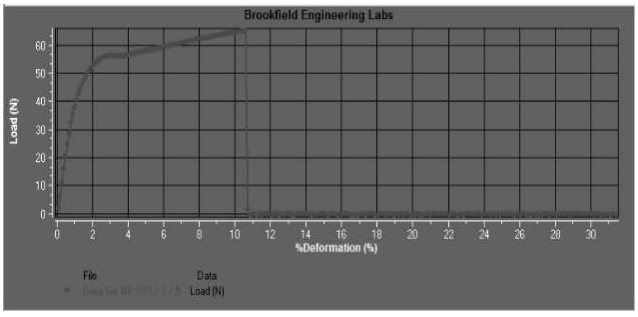

Fig. 3. Variation of tensile stress with respect to tensile strain for sample 6

Table 3. Thickness and colour of the films based on chitosan and lemongrass essential oil

Sample	Sample composition (ml)	Thickness (mm)	L	a	b
S1	100	0.05	22.86	-0.39	0.27
S2	70	0.03	21.42	-0.08	0.11
S3	50	0.02	21.37	-0.19	-0.38
S4	130	0.02	14.34	-0.51	-0.71
S5	150	0.03	20.40	-0.34	0.19
S6	300	0.05	20.53	-0.36	0.34
S7	75	0.025	18.39	-0.25	-0.50
S8	100	0.02	17.41	-0.46	-0.40
S9	100	0.04	19.38	-1.15	9.26
S10	75	0.04	14.19	-0.31	-0.53
S11	200	0.05	18.28	-0.77	1.43

Table 4. Mechanical properties of tensile strength, elasticity and puncture force of the films based on chitosan and lemongrass essential oil

Sample	Sample composition (ml)	Peak load at tensile force (N)	Deformation at peak load (mm)	Puncture force (N)
S1	100	51.583	2.93	16.818
S2	70	24.173	1.68	8.875
S3	50	16.671	1.34	4.609
S4	130	32.950	2.79	13.337
S5	150	73.256	12.45	20.153
S6	300	65.21	10.14	16.230
S7	75	12.896	1.39	13.239
S8	100	25.841	3.20	10.885
S9	100	50.72	2.82	19.564
S10	75	49.426	2.48	12.847
S11	200	46.41	4.9	11.604

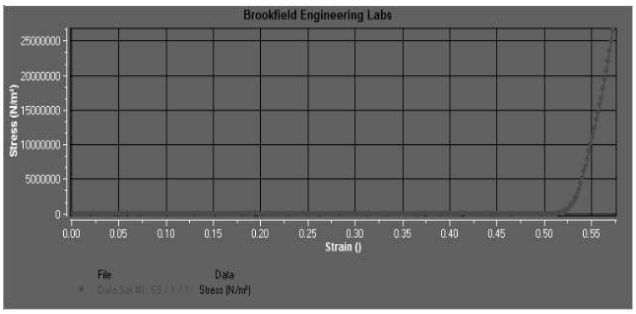

Fig. 4. Stress-strain curve for the puncture process for sample 5

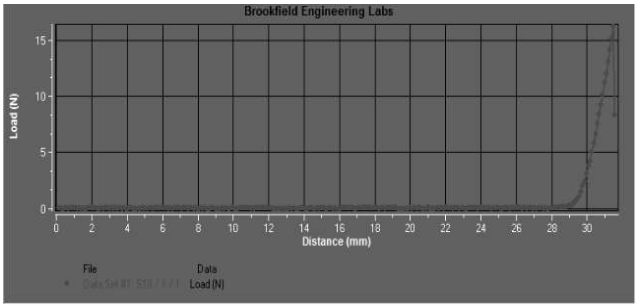

Fig. 5. Stress-strain curve for the puncture process for sample 6

Fig. 6. Biodegradability of film

Biodegradability: Biodegradable film prepared from chitosan and lemongrass essential was degraded about 0.03 g for every 10 days and was completely degraded after 4 months. Biodegradable film was kept in soil in the month of September 2022 and it was completely degraded in soil by the end of December 2022. Hence, film fabricated is biodegradable in nature and eco-friendly.

CONCLUSION

Biodegradable film from chitosan and lemongrass essential oil was developed and its physical and mechanical properties were tested. Major findings of this study were, sample with glycerol took more time for drying than usual, and the sample with coconut oil is not recommended, as the oil is separated and formed on the surface of the film. Sample with lime yellow food colour has pleasing appearance with good mechanical properties and the sample with beetroot juice has good mechanical strength but the colour of it is not durable. Best films were resulted on polypropylene petri dish and polypropylene sheets. Based on the observations and results, sample S5 is the best composition. Hence, for 150 ml of film forming solution, 500 cm^2 polypropylene sheets can be sufficient to provide required thickness and strength. It is not recommended to dry more quantity solution on a same sized mould, as it will be wasted.

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Utilization of Waste Unripe Mango for Preparation of Candy with Enhanced Bioactive and Mineral Composition

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***Abstract*:** In the present study, waste (dropped) raw/unripe local mangoes were utilized to prepare highly nutritious fruit candy as functional food. The raw mango pulp was blended with different concentration of gelatin, pectin, brown sugar (gur) and sugar to prepare candy having chewy texture. The fruit candy was analyzed for its bioactive components and overall acceptability scores during storage under ambient conditions. Significant decrease in total phenols (98.92 to 95.17 GAE/100g), antioxidant activity 16.64 to 15.57 %), ascorbic acid (31.47 to 26.31 mg/100g) and total flavonoid content (15.31 to 14.69 mg Catechin/100 g) of raw mango candy was observed during storage period of 90 days, Highest amount of mean calcium (48.82 mg/100g) and phosphorus content (27.86 mg/100g) were in T_6(RMP + 4.5 g gelatin + 3.5g pectin + 45g brown sugar). Sensory evaluation of raw mango candies showed that candy prepared using 4 g gelatin, 3g pectin and 40g sugar scored the best with respect to overall acceptability scores. Thus, mango fruit candy having rich flavour of raw/unripe mango can emerge as a highly acceptable confectionery product liked by almost all age groups as a snack for gaining quick energy thereby adding economic value and enhanced utilization of the waste mango and higher monetary returns to the farmers/small scale food processors.

Keywords: Unripe mango, Gelatin, Pectin, Candy, Bioactive component, Overall acceptability

Fruits are highly perishable because of various enzymatic as well as non-enzymatic reactions that occur during different stages of fruit maturation and storage causing changes in nutritional and sensorial properties (Baldwin and Bai 2010). Providentially, mango fruit can be used in all stages of maturity as a dessert, table fruit and can be processed into numerous value added products. Different conventional mango products have been developed so far and significant demand has been built up by the processing industry, both for domestic and export market (Ravani and Joshi 2013). The international market has become more competitive and many other mango producing countries are also entering the market. Therefore, there is a pressure on the industry for the development of newer category of products, so as to hold on to the monopoly in the international market. Fully mature but unripe mango fruits which drop down from the trees are acidic in taste and are generally used to prepare products like pickles, chutney, *amchoor* etc. These fresh fruit have a very poor shelf life and post-harvest losses occur due to numbers of problems posing difficulty in preserving of the freshness of produce for longer duration. With increasing awareness regarding the food value and dietary significance of various food constituents, people are now highly conscious in selecting food products. The general tendency of the consumers has shifted towards selecting those products prepared from natural ingredients. Local mango fruits are poor in size, having small amount of pulp and does not have market value besides having limited shelf life. But the nutritional composition and flavour is remarkable and can be effectively used to prepare fruit candy. Fruit candies can be better utilized as a vehicle to promote consumption and utilization of local mango (which usually drop from trees). The osmo-dried or fruit candies are a popular and highly acceptable confectionery products and are liked by almost all age groups as a snack for gaining quick energy. Fruit toffees contain original nutrients like vitamins and minerals present in the real fruit and are nutritionally superior to those prepared from sugar or syrup. Therefore study was planned to utilize waste unripe/raw mango to produce pulpy toffee with chewable texture using gelatin and pectin along with sugar/honey as sweetening agents.

MATERIAL AND METHODS

Preparation of pulp: The raw mangoes were peeled and converted into pulp using mixer grinder. The pulp was divided into two lots. One lot was cooked with sugar (100g/kg pulp) and the second lot was cooked using brown sugar i.e. *gur* (100g/kg pulp). The pulp was cooled and stored in jar under refrigerated condition for further use.

Preparation of raw mango candy: The raw mango pulp

(RMP) was mixed with different ingredients as per the treatment (Table 1). The candy was prepared as per the procedure described by Revanwar and Sakhlae (2003) with certain modification. The prepared mango pulp was heated till it remained one half of its original volume and other ingredients viz. pectin, gelatin, sugar/brown sugar were added as per the treatment details. The pulp was further cooked (concentrated) until one third of its original volume. Addition of edible fat (15g) and skim milk powder (50ml) was done after dissolving in small amount of warm water. The pulp was further concentrated up to 78° Brix and then molded into cuboid shape (candy shape approximately 3g in weight). After cooling it for 2 hours, the candy was wrapped in butter paper and transparent plastic film and finally placed in laminated pouches (100g) and stored in air tight containers.

Bioactive Components

Ascorbic acid: Titrimetric method using 2,6-dichlorophenol indophenol dye was used to estimate ascorbic acid (AOAC 2012).

Total phenols: The total phenolic content was determined by method of Folin-Ciocalteu (FC) which is an electron transfer based assay (Ahmed and Abozed 2015).

Total flavonoids: Total flavonoids content (mg Catechin/100 g) was estimated using aluminum chloride method (Zhishen et al 1999).

Total carotenoids: Two grams of sample was macerated in 10 ml of 80 per cent acetone in pestle and mortar and centrifuged at 5000 rpm for 15 minutes. The remaining pellets in the centrifuge tube were repeatedly extracted with 10 ml of 80 per cent acetone until it became colourless. All the extracted supernatant (acetone extracts) were pooled together and its final volume was made up to 100 ml with 80 per cent acetone. The filtrate was then transferred to separating funnel. Added 10 to 15 ml of petroleum ether and the separating funnel was shaken for mixing of pigments into petroleum ether phase. The petroleum ether extract was shaken layer were measured using UV-spectrophotometer at 440 nm using petroleum layer as a blank (Carvalho et al 2012). The results were calculated as µg/100g.

$$\text{Carotene} = \frac{\text{Conc. of carotene in soln. from standard curve} \times \text{Final volume} \times \text{Dilution} \times 100}{\text{Weight of sample}}$$

Antioxidant activity: Free radical scavenging activity was determined by DPPH (diphenylpicryhydrazyl) method. Five hundred micro liters of 0.5 Mm DPPH solution and 2ml of 80 per cent methanol aqueous solution were mixed with 25µl of methanolic extract of sample, and absorbance were determined under 517nm blank as 80 per cent methanol and tris buffer after maintaining at 20°C for 30 minutes. The free radical scavenging activity was evaluated by comparing the absorbance of the sample solution with control solution to which distilled water was added instead of sample (Luo et al 2009).

$$\text{Radical scavenging activity (\%)} = \frac{\text{Control OD (0 min) - Sample OD (30 min)} \times 100}{\text{Control OD (0 min)}}$$

Minerals: Phosphorus content was determined with the help of Spectrophotometer (UV-1601) by using Vandate-molybedete reagent yellow colour method described by Ahmed and Abozed (2015). The phosphorus content was calculated by plotting against the standard curve obtained by taking known amount of potassium di-hydrogen phosphate (KH_2PO_4) salt. The result was expressed as mg/l00g. For estimation of calcium content a known volume of sample (1ml) extract was titrated with standard EDTA (N/50) solution using ammonium perpurate (Mure oxide) as an indicator in the presence of 4 N NaOH solution. The end point is a change in color from orange-red to purple.

$$\text{Meq Ca/100g of sample} = \frac{\text{Volume of EDTA x Volume of sample made x N of EDTA} \times 100}{\text{Weight of sample} \times \text{volume aliquot (ml)}}$$

Sensory evaluation: The samples were evaluated for acceptability by semi-trained panels of 7-8 judges using 9 point hedonic scale assigning scores 9 - like to 1- dislike extremely The score of 5.5 and above was considered acceptable (Amerine et al 1965).

RESULTS AND DISCUSSION

Bioactive composition of fresh raw mango fruit: Illustrates bioactive component and Mineral characteristics of fresh raw mango fruit. The antioxidant percentage in fresh raw mango fruit was 12.06 and total flavonoids of 21.16 mg Catechin/100 g) (Table 1).

Effect of pectin, gelatin and sweetening agents on bioactive composition of raw mango fruit candy: Ascorbic acid content of raw mango candy showed a decreasing trend over storage period of 90 days at ambient temperature. Storage had significant effect on ascorbic acid content of raw mango blended candy with highest mean ascorbic acid content of 31.47 mg/l00g at zero day which decreased to 26.31 mg/100 after 90 days storage. After 90 days of storage the highest ascorbic acid content of 27.17 mg/l00g was in T_2 (RMP+ 4g gelatin + 3g pectin + 40g sugar) and lowest ascorbic acid content of 26.01 mg/l00g was in T_4 (RMP+ 3.5g gelatin + 2.5g pectin + 45g brown sugar).

Significant reduction in vitamin C content of guava jelly bar and blended toffee (bottle gourd and strawberry) due to oxidation of ascorbic acid into dehydro ascorbic acid by oxidase enzyme like ascorbic acid oxidase during storage (Kuchi et al 2014, Norzom et al 2018). The ascorbic acid content decreased more rapidly in the initial stages but the decrease was slow in the later stages with increase in storage period (Nayak et al 2012). The total flavonoid content decreased with the advancement of storage period. After 90 days of storage, treatment T_6 recorded the highest flavonoid content of 14.86 mg Catechin/100g and treatment T_1 lowest flavonoid content of 14.54 mg Catechin/100g. Highest mean total flavonoid content of 15.31mg Catechin/100gwas at initial day of storage which decreased to 14.69mg Catechin/100g after 90 days storage. Decrease in flavonoid content might be due to ingress of oxygen and dilution of flavonoid content due to moisture gain during the storage of candies (Mir et al 2015). The results are in close proximity with the findings of Yadav (2020) on jamun and bael blended cheese.

Significant decrease in phenol content was observed during storage of raw mango candy and the total phenol decreased from initial mean value of 98.92 to 95.17 GAE/100g during 90 days storage (Table 2). After 90 days of storage, the highest total phenol content of 100.05 mg/100g was noticed in treatment T_6whereas, lowest total phenol content of 91.72 GAE/100g was in treatment T_1). Accumulation of phenols during the storage of raw mango candy has been observed by some researchers. The phenolic compounds are highly volatile and are easily oxidized to give brown product of high molecular weight. The decline in total phenols during the period of storage might be owing to their condensation into brown pigments. Decrease in the total phenolic content with increased storage period was observed in case of researches carried out on freeze dried whole strawberries (Bandral et al 2022). Decrease in **t**he total carotenoids content was noticed with the advancement of storage and after 90 days treatment T_6 (RMP+ 4.5g gelatin + 3.5g pectin + 45g brown sugar) recorded the highest carotenoid content of 62.68 µg/100g and T_1 (RMP+ 4g gelatin + 3g pectin + 45g brown sugar) lowest carotenoid content of 60.49 µg/100g. In the presence of light, the carotenoids were destroyed or altered by acids to form cis-isomers form all the trans structure. The pigments were easily oxidized in the presence of oxygen. The oxygen content in the storage medium is the crucial factor acting on carotene discoloration and a small percentage of oxygen contact with carotene had a dramatic effect on its shelf life (Kumar et al 2017). Trilokia et al (2022) also reported significant reduction in total carotenoid content of freeze dried carrot pomace with the advancement in storage period. Antioxidant activity of raw mango showed a decreasing trend during storage and there was significant influence of storage and the results for interaction between treatments and storage were also found to be significant. The mean antioxidant activity decreased from 16.64 to 15.57 per cent during 90 days of storage. Phenolic compounds and ascorbic acid content were responsible for the antioxidant activity of fruits. This loss in antioxidant activity could be attributed to oxidation or loss of ascorbic acid and phenolic compounds with the passage of time in quince candy during storage at ambient condition (Mir et al 2015).

Mineral composition of raw mango candy: The phosphorus contents of raw mango candy decreased significantly during 90 days of storage period and the lowest mean phosphorus content of 6.69 mg/100g was in treatment T_1 (RMP+ 3.5g gelatin + 2.5g pectin + 40g sugar) whereas highest value of 27.86 was recorded in treatment T_6 (RMP+ 4.5g gelatin + 3.5g pectin + 45g brown sugar). Similar results were reported while developing fruit based preserved products (wood apple fruit bar, strawberry bottle gourd blended fruit toffee) and the possible reason for the decrease might be due to its heat sensitiveness even at the ambient

Table 1. Bioactive and Minerals composition of raw mango pulp (RMP)

Parameter	Content
Ascorbic acid (mg/100g)	29.55
Total carotenoids (µg/100g)	68.45
Total phenols (GAE/100g)	113.50
Total flavonoids (mg Catechin/100 g)	21.16
Total Antioxidant activity (%)	12.06
Phosphorus (mg/100g)	19.34
Calcium (mg/100g)	10.00

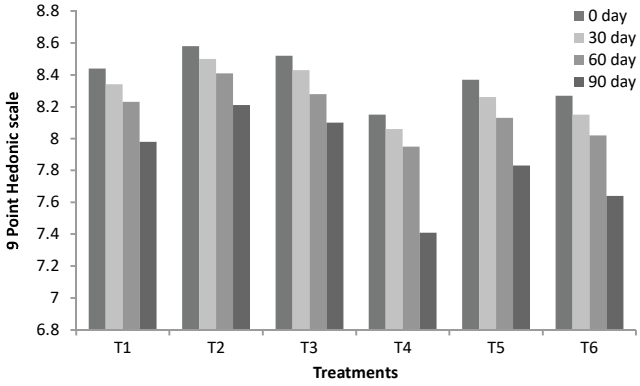

Fig. 1. Effect of various treatments and storage periods on overall acceptability scores of raw mango candy

temperature which causes the destruction of minerals during storage. There was significant decrease in the calcium content of raw mango candy with the advancement of storage period and it decreased from 38.15 to 36.82mg/100g during 90 days of storage (Table 3). After 90 days of storage, T_1 recorded the lowest calcium content of 24.24 mg/100g whereas highest calcium content of 48.82 mg/100g was in T_6. Calcium content of candy was significantly influenced by storage period and the results for interaction between treatments and storage. These findings are in line with those observed for bael-jamun blended cheese (Yadav 2020), iron rich toffees (Mewada et al 2013) and chickpea nuggets (Choton et al 2022).

Overall acceptability raw mango candy: General decrease in overall acceptability scores was observed in all the treatments with the advancement of storage period (Fig. 3). After 90 days of storage the highest overall acceptability score of 8.21 was in T_2 (RMP+ 4g gelatin + 3g pectin + 40g sugar), whereas, the lowest over all acceptability score of 7.41 was in T_4 (RMP+ 3.5g gelatin + 2.5g pectin + 45g brown sugar). Storage studies on guava papaya mix toffee have indicated a

Table 1. Effect of various treatments and storage on Ascorbic acid and Total flavonoids content of raw mango candy

Treatments	Ascorbic acid (mg/100g)					Total flavonoids (mg atechin/100g)				
	Days after storage					Days after storage				
	0	30	60	90	Mean	0	30	60	90	Mean
T_1 (RMP + 3.5g gelatin + 2.5 g pectin + 40g sugar)	55.22	53.71	52.45	51.19	53.14	15.10	14.98	14.72	14.54	14.83
T_2 (RMP + 4g gelatin + 3 g pectin + 40g sugar)	52.65	51.18	49.86	48.71	50.60	15.19	15.07	14.98	14.60	14.96
T_3 (RMP+ 4.5g gelatin + 3.5 g pectin + 40g sugar)	50.75	49.35	48.10	46.98	48.79	15.25	15.16	15.07	14.79	15.07
T_4 (RMP + 3.5g gelatin + 2.5 g pectin + 45g brown sugar)	45.40	44.05	42.85	41.76	43.51	15.31	15.19	15.03	14.58	15.02
T_5 (RMP + 4g gelatin + 3g pectin + 45g brown sugar)	43.81	42.55	41.41	40.39	42.04	15.48	15.30	15.08	14.77	15.16
T_6 (RMP + 4.5g gelatin + 3.5g pectin + 45g brown sugar)	42.41	41.19	40.12	39.22	40.73	15.51	15.38	15.25	14.86	15.25
Mean	48.37	47.01	45.79	44.71		15.31	15.18	15.02	14.69	

RMP	Raw Mango Pulp	RMP	Raw Mango
Effects	CD ($p \leq 0.05$)	Pulp	
Treatment	0.10	Effects	CD ($p \leq 0.05$)
Storage	0.03	Treatment	0.03
Treatment x Storage	0.07	Storage	0.02
		Treatment x Storage	0.06

Table 2. Effect of various treatments and storage on Total phenols, Total carotenoids and Total antioxidant activity of raw mango candy

Treatment	Total phenols (GAE/100g)					Total carotenoids (µg/100 g)					Total antioxidant activity (%)				
	Days after storage					Days after storage					Days after storage				
	0	30	60	90	Mean	0	30	60	90	Mean	0	30	60	90	Mean
T_1	93.96	93.76	92.52	91.72	92.99	61.81	61.33	60.09	58.74	60.49	15.81	15.34	15.09	14.74	15.24
T_2	95.44	95.24	94.90	92.48	94.51	62.17	61.69	60.33	59.97	61.04	16.17	15.69	15.33	14.97	15.54
T_3	97.76	97.51	96.19	94.83	96.57	62.41	62.05	61.30	60.21	61.49	16.40	16.05	15.69	15.21	15.84
T_4	99.96	99.67	97.31	95.93	98.21	62.65	62.17	61.64	60.82	61.81	16.64	16.17	15.81	15.69	16.08
T_5	101.11	100.82	98.43	96.02	99.09	63.36	63.00	62.70	61.40	62.61	17.36	17.00	16.78	16.31	16.91
T_6	105.28	104.89	102.48	100.05	103.18	63.48	63.36	62.88	61.00	62.68	17.48	17.25	16.94	16.50	17.04
Mean	98.92	98.65	96.97	95.17		62.65	62.26	61.49	60.35		16.64	16.25	15.94	15.57	

Effects	CD ($p \leq 0.05$)	Effects	CD ($p \leq 0.05$)	Effects	CD ($p \leq 0.05$)
Treatment	0.04	Treatment	0.02	Treatment	0.02
Storage	0.02	Storage	0.03	Storage	0.04
Treatment x Storage	0.07	Treatment x Storage	0.07	Treatment x Storage	0.08

Table 3. Effect of combination of pectin and gelatin on calcium and phosphorus content of raw mango candy

Treatments	Calcium (mg/100g)					Phosphorus (mg/100g)				
	Days after storage					Days after storage				
	0	30	60	90	Mean	0	30	60	90	Mean
T_1	25.76	25.23	24.83	24.24	25.02	6.89	6.75	6.64	6.49	6.69
T_2	27.03	26.81	26.44	25.60	26.47	7.23	7.17	7.08	6.98	7.12
T_3	27.73	27.39	26.93	26.45	27.13	7.42	7.33	7.21	7.08	7.26
T_4	48.48	48.21	47.74	47.35	47.95	27.62	27.55	26.96	26.37	27.13
T_5	49.65	49.33	48.82	48.48	49.07	27.94	27.85	27.59	27.30	27.67
T_6	50.23	49.85	49.19	48.82	49.52	28.09	27.99	27.71	27.64	27.86
Mean	38.15	37.80	37.33	36.82		15.42	15.33	15.10	14.84	
RMP	Raw Mango Pulp					RMP				Raw Mango
Effects	CD ($p \leq 0.05$)					Pulp				
Treatment	0.12					Effects				CD ($p \leq 0.05$)
Storage	0.03					Treatment				0.15
Treatment x Storage	0.07					Storage				0.01
						Treatment x Storage				0.07

decrease in the score of different parameters of raw mango blended candy, irrespective of treatments during storage which might be attributed to change in their objective characteristics like loss of colour pigments, breakdown of insoluble solids, change in sugar acid ratio and overall quality loss (Mewada et al 2013). Decreasing trend in organoleptic scores of mango-pumpkin blended toffees (Choudhary 2020), aonla-mango mixed fruit slab (Verma and Chopra 2010) during storage has been reflected in some studies and the product maintained its acceptability up to seven months at ambient storage.

CONCLUSION

On the basis of sensory evaluation raw mango pulp + 4g gelatin + 3g pectin + 40g sugar was the best treatment. The candy can be stored at ambient conditions for 90 days without much loss in nutritional quality. Therefore, by preparing raw mango products, the processing industry can fulfill the dual purpose of better use of these perishable fruits (having high therapeutic value) thus lowering post harvest losses and will also give good returns to the growers.

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Evaluation of Infiltration Indices Based on Double Ring Infiltrometer

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***Abstract*:** Infiltration into the soil is the key parameter for water availability to rootzone of the crop. Infiltration rate may be affected with respect to different soil and climatic conditions. Therefore, information of infiltration rate is important to evaluate crop water requirement and irrigation purposes. The present study used double ring infiltrometer to evaluate infiltration capacity for 10 locations in Kalyanpur block of Bihar. The infiltration rate was estimated by Green Ampt model, Philips model, Kostiakov model and Hortons model for all locations. The slope and intercept parameters were evaluated by regression analysis of the observed data. The performance of the all models was evaluated by correlation coefficient (r), root mean square error (RMSE), mean absolute error (MAE), Nash-Sutcliffe efficiency (NSE) and Wilmot Index (WI). The Green Ampt model was superior at eight sites while Philip's and Kostiakov models at one site each. Horton's model performed poorly at all sites. Thus, the study showed that the Green Ampt model may applicable for infiltration rate within Kalyanpur block of Bihar.

***Keywords*:** Infiltration rate, Double ring infiltrometer, Green Ampt model, Philips model, Kostiakov model, Hortons model, Kalyanpur block

India is predominantly a farming nation where agriculture is the primary or secondary source of income for about 75 % of the rural population and is the second biggest producer of agricultural products in the world. India's easternmost state, Bihar, is situated between latitudes 24°20'10" and 27°31'15"N and longitudes 83°19'50" and 88°17'40"E. The average elevation of the land in Bihar is 173 feet above sea level. Soils in Bihar can be broadly divided into seven types, which are mainly alluvial soil 50 % founds in Bihar. Others soils types are laterite soil, piedmont swamp soil, terai soil, alluvial soil, balsundari soil, tal soil and balthar soil. Infiltration characteristics of soil is very useful in irrigation management, drainage engineering, hydrology and watershed management. Study of various infiltration models are important for the hydrological modeling. Numerous aspects of the soil, such as its structure, hydraulic conductivity, and porosity, in addition to its present moisture content, surface conditions, and vegetation cover have an impact on this rate (Dunkerley 2012, Angelaki et al 2013, Wang et al 2015, Sihag et al 2019). Once the saturation infiltration rate has reached for the specific soil, this rate stabilizes. Infiltration rate varies with the soil type depending upon its composition such as clay soil has a low infiltration rate, compared to sandy soil and Loamy soil has a moderate infiltration rate. The infiltration rate is calculated using infiltrometer. A Double-Ring Infiltrometer is one of the most popular infiltrometer designs for determining a 1-dimentional flow (Cervenanska and Rusnak 2018). To assess the rate of infiltration, many scientists presented several infiltration models) such as Kostiakov Model, Modified Kostiakov Model, Horton's Model, Green-Ampt Model, Philip's Model, Holton's Model, Modified Lewis Model, Novel Model (Sihag et al 2017, Vand et al 2018) . Since North Bihar soil fertility is high rather than south Bihar and there is an absence of specific information on infiltration rate, the present field investigations was carried out to evaluate the best-fit infiltration models used to estimate the final infiltration rate of soils in North Bihar.

MATERIAL AND METHODS

Study area: The study area (Samastipur) is located in the North-West Alluvial Plains and is renowned for its abundant alluvial soil and *Rabi* crops. The present field investigations were conducted at farmers' fields from the villages-Kalyanpur, Akbarpur, Tira, Rampura, Ladaura, Mirzapur, Basudeopur, Birsingpur, Kabargama and Phulhara of Samastipur district, Bihar (Fig. 1) during April 2022 to July 2022. The district is situated between 25°30' to 26°05' N latitude and 85°37' to 86°23' E longitude having a total geographical area of 2,904 km^2. The Samastipur district receives 1142 mm of rainfall annually. The mean daily minimum temperature varies from 7 and 10 °C and the mean daily maximum temperature from 20 and 25 °C in winter. The major cropping sequences of Samastipur district are rice-wheat, maize-wheat and maize-potato. Table 1 showed the coordinate of all locations.

METHODOLOGY

The double ring infiltrometer method (Thomas et al 2020)

was used to determine the soil infiltration rate for all the selected sites. The double ring infiltrometer consists two concentric metallic cylinders made of a 2 mm thick rolled sheet (Fig. 2). Only the inner cylinder, which had a 30 cm diameter, was used to measure infiltration. The buffer pond was formed by using outer cylinder, which has a 60 cm diameter. Other equipment used for infiltration test were driving plate, driving hammer, stopwatch, measuring scale (e.g., 300 mm ruler) and bucket.

The observations were continued until the rate of infiltration reached nearly constant (Table 2). The following formula is used to determine the infiltration rate:

$$\text{Infiltration rate (mm h}^{-1}) = \frac{\text{Initial water depth (mm)} - \text{Final water depth (mm)}}{\text{Time required (h)}}$$

Prediction models for infiltration rates: The models used in this present study to assess the rate of infiltration are Green-Ampt (1911), Phillips (1957), Kostiakov (1932) and Horton (1940) model due to its simplicity and ease of computation. The infiltration models applied in this work are briefly described below:

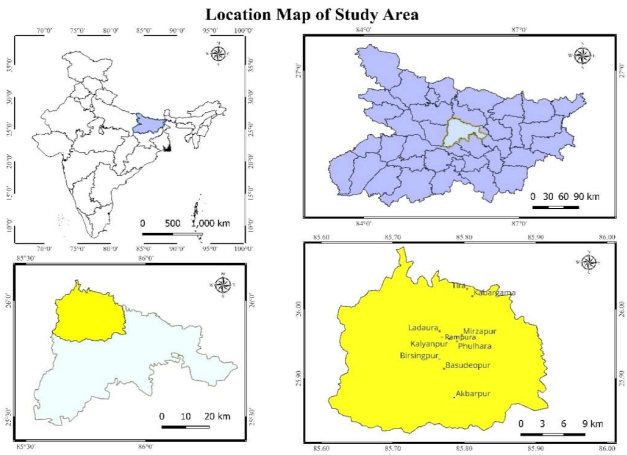

Fig. 1. Study area

Table 1. Location coordinates of experimental plots

Site No.	Location	Latitude	Longitude
1	Kalyanpur	25.96	85.77
2	Akbarpur	25.92	85.77
3	Tira	26.03	85.80
4	Rampura	25.96	85.77
5	Ladaura	25.97	85.77
6	Mirzapur	25.80	85.65
7	Basudeopur	25.88	85.79
8	Birsingpur	25.93	85.77
9	Kabargama	26.02	85.81
10	Phulhara	25.94	85.79

Green-Ampt Model: Green-Ampt model is the earliest physically based conceptual infiltration model. This equation is considered in the form

$$f_p = m + n/F_p$$

Where, f_p = infiltration rate (mm h^{-1}); F_p= cumulative infiltration capacity (mm); m and n = Green-Ampt parameters of the infiltration model. Plotting f_p values against $1/F_p$ and then drawing the best-fitting straight line between the plotted points. Coefficients m and n are, respectively, the intercept and slope of the line.

Philips model: The vertical penetration of water into a uniform sandy soil profile is simulated by this model. Philip's equation is considered in the form

$$f_p = 1/2\ st^{-1/2} + K$$

Where, f_p = infiltration rate (mm h^{-1}); S = Sorptivity parameter that is function of soil matrix forces (mm $h^{-0.5}$); K = a constant (mm h^{-1}). Plot the actual values of f_p vs. $t^{-0.5}$, and then use the best-fitting straight line to connect the points. This line will have K as the intercept and (s/2) as the slope.

Kostiakov model: A simple and general form of infiltration model. In order to determine cumulative infiltration capacity, Kostiakov presented the following equation

$$F_p = at^b$$

Where, F_p = Cumulative infiltration (mm); t = Time after infiltration starts (h); a & b = constants with a > 0 and 0 < b < 1. The same parameters were used in the logarithmic form of the equation by Criddle et al in 1956.

$$\text{Ln } (F_p) = \text{ln } a + b \text{ ln } (t)$$

Plotting log (F_p) vs. log (t) reveals the parameter values for a and b; the best-fitting straight line across the plotted points gives ln (a) as the intercept and b as the slope. The higher the value of b, the steeper the slope and infiltration rate fall at an exponentially faster rate.

Fig. 2. Double ring infiltrometer

Horton model: Horton noticed that the infiltration capacity gradually reduced until it was close to a minimum constant rate. Horton's equation is considered in the form

$$f_p = f_c+(f_0-f_c)\, e^{-K_h t}$$

Where, f_p = Infiltration capacity or potential infiltration rate (mm h^{-1}); f_c = Final constant infiltration rate or ultimate infiltration capacity (mm h^{-1}); f_o = Initial infiltration capacity (mm h^{-1}); K_h = Horton's decay coefficient which depends upon soil characteristics and vegetation cover; t = Time after start of infiltration (h). By taking the natural log of each side and subtracting f_c from both sides of the equation, the equation for a straight line is obtained.

$$\ln (f_p - f_c) = \ln (f_0-f_c) (-K_h t)$$

Plot ln (f_p - f_c) vs. t, and the intercept of the best-fit straight line between the plotted points is given by ln (f_p - f_c), with K_h being the slope of the line.

Performance evaluation parameters: To assess the performance of infiltration models' different statistical analysis for the various depths observations of the infiltration rate were calculated by following statistical parameters:

Correlation coefficient: The degree of correlation between the relative motions of two variables is measured statistically using the coefficient of correlation. The formula for calculating the correlation coefficient (r) is

$$r = \frac{n\sum ab - (\sum a)(\sum b)}{\sqrt{n(\sum a^2) - (\sum a)^2}\sqrt{n(\sum b^2) - (\sum b)^2}}$$

Where, a is the actual values and b is the estimated values.

Root mean square error (RMSE): The RMSE is calculated as

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}(\sum_{i=1}^{n}(a_i - b_i)^2}$$

Where, N is the total number of observations, b_i is the observed values of the cumulative infiltration depth, and a_i is the predicted value.

Mean absolute error (MAE): The difference between the observed value and the predicted value is measured as the mean absolute error. This error is estimated as

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{n}(a_i - b_i)^2$$

where, a is the predicted and b is observed values of the infiltration rate and N is the number of observations.

Nash sutcliffe efficiency (NSE): The NSE stands for the average difference between the infiltration models predicted and observed values. The NSE is calculated as

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(a_i - b_i)^2}{\sum_{i=1}^{n}(a_i - \bar{a})^2}$$

where, a_i represents the predicted values and b_i represents the observed values of the cumulative infiltration depth.

Willmott index (WI): WI is a simplified representation of the degree of agreement between predicted and observed values and can be written as

$$W = 1 - \frac{\sum_{j=1}^{n}\left[I(p)_j - I(m)_j\right]^2}{\sum_{j=1}^{n}\left[\left|I(p)_j - \overline{I(m)_j}\right| + \left|I(m)_j - \overline{I(m)_j}\right|\right]^2}.$$

where, p_j is the Predicted and m_j is the observed values.

RESULTS AND DISCUSSION

Cumulative infiltration (F_p) and infiltration rate (f_p) for given locations: Based on the amount of water added (ml) added at different time interval (min), the cumulative infiltration depth (mm) and infiltration rate (mm h^{-1}) of the soil were evaluated for all given locations (Fig. 3). The infiltration rate curve was observed initially very high and steadily declined over time, based on the overall findings. The cumulative infiltration depth was initially increased steadily with constant final values for each given location. Similar result was found by (Yang et al 2020). The initial infiltration rate (mm h^{-1}) varied between 6.96 and 12.99 (Kalyanpur). Meanwhile, final steady infiltration rate (mm h^{-1}) ranged between 0.10 Ladaura and Kabargama and 0.18. Variations in infiltration rates are facilitated by extensive root system and animals burrowing in the soil, inadequate prewetting, and soil disturbance by the infiltration ring (Thomas et al 2022).

Determination of slope and intercepts of infiltration models: The slope and intercept parameters were evaluated by transforming the infiltration models into straight-line equations (Table 3). The slope values for the Green-Ampt model at a given location ranged from 0.08 (Kalyanpur) to 16.36 (Kabargama). The highest slopes values for the Philip

Table 2. Initial and final infiltration rate of soil of the study area

Site No.	Locations	Initial infiltration rate, f_p (mm h^{-1})	Final infiltration rate, f_p (mm h^{-1})
1	Kalyanpur	12.99	0.18
2	Akbarpur	10.19	0.12
3	Tira	10.11	0.12
4	Rampura	5.91	0.12
5	Ladaura	9.77	0.10
6	Mirzapur	6.79	0.12
7	Basudeopur	6.96	0.12
8	Birsingpur	7.39	0.12
9	Kabargama	9.73	0.10
10	Phulhara	7.13	0.12

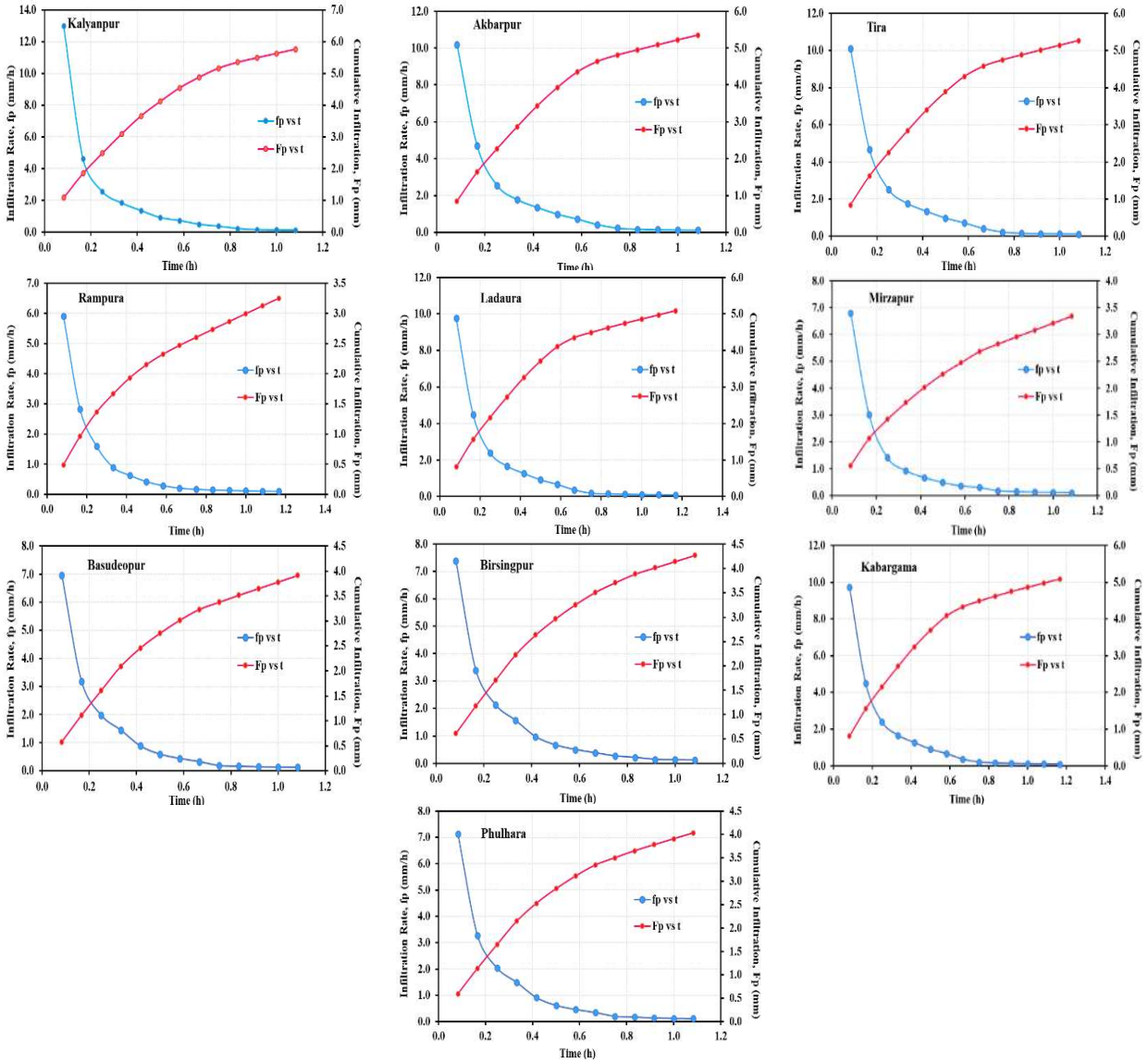

Fig. 3. Cumulative infiltration (F_p) and infiltration rate (f_p) vs time (h) for given locations

Table 3. Slope and intercepts of infiltration models of the study area

Location	Green-Ampt model		Philip model		Kostiakov model		Horton model	
	Slope (n)	Intercept (m)	Slope (s)	Intercept (k)	Slope (b)	Intercept (a)	Slope (k_h)	Intercept (f_0-f_c)
Kalyanpur	16.36	-3.05	4.72	-5.37	0.66	1.81	-4.85	2.27
Akbarpur	10.23	-1.77	3.89	-4.29	0.71	1.76	-5.16	2.26
Tira	10.07	-1.78	3.86	-4.26	0.71	1.74	-5.24	2.27
Rampura	3.50	-1.09	3.89	-4.29	0.68	1.15	-3.48	1.27
Ladaura	9.46	-1.78	3.89	-4.29	0.68	1.15	-4.27	2.07
Mirzapur	4.62	-1.47	3.89	-4.29	0.67	1.23	-1.66	-1.99
Basudeopur	4.72	-1.09	3.89	-4.29	0.73	1.43	-3.99	1.72
Birsingpur	5.27	-1.08	3.89	-4.29	0.75	1.52	-4.03	1.83
Kabargama	0.08	-0.14	3.64	-3.96	0.68	1.66	-4.24	2.06
Phulhara	4.94	-1.09	2.73	-2.96	0.73	1.46	-4.05	1.78

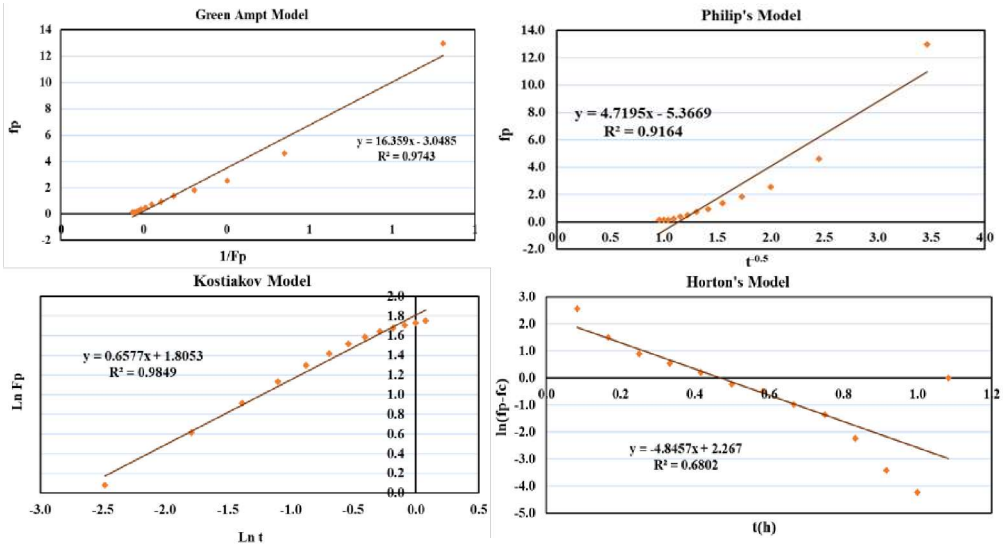

Fig. 4. Fitting of (a) Green Ampt, (b) Philips, (c) Kostiakov and (d) Hortons equation for Kalyanpur village

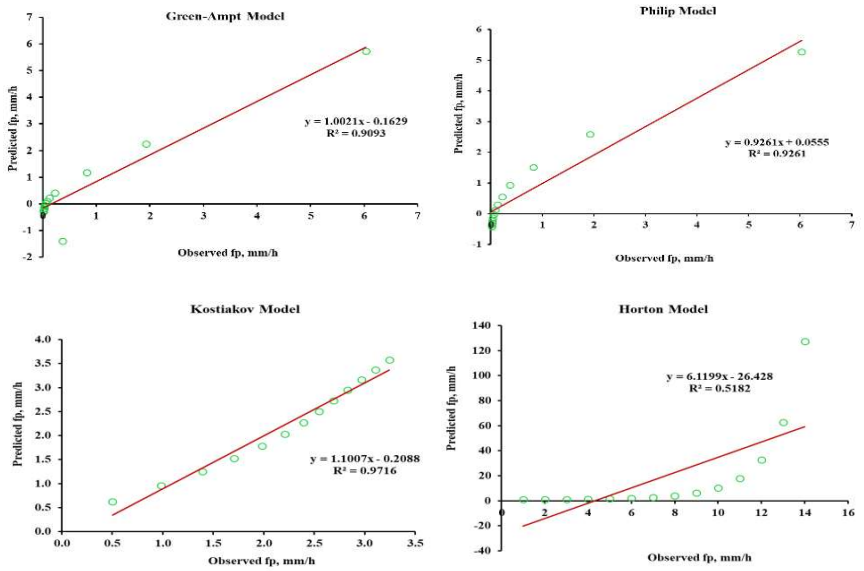

Fig. 5. Predicted and observed value of IR (mm h^{-1}) for Kalyanpur village

model were 4.72 in Kalyanpur villages, while the lowest 2.73 in Phulhara village. The slope of the Kostiakov model varied from 0.66 (Kalyanpur) to 0.75 (Birsingpur). For Horton's model, negative values of the slope were in the range of -5.16 (Akbarpur) to -1.66 (Mirzapur). Further, the intercept values for the Green-Ampt model, Philip model, Kostiakov model and Horton model were obtained in the range of -3.05 to -0.14, -4.29 to -2.96, 1.15 to 1.81 and -1.99 to 2.27, respectively. Figure 4 showed the fitting of (a) Green Ampt, (b) Philips, (c) Kostiakov and (d) Hortons model of Kalyanpur village.

Performance evaluation of developed infiltration models at the given locations: Based on the slope and intercept values of different infiltration models, the estimation of infiltration rate was evaluated using the Green-Ampt, Philip, Kostiakov and Horton model. The performance evaluation of all developed models between observed and predicted infiltration rate were analyzed based on the highest values correlation coefficient (r), Nash Sutcliffe efficiency (NSE), and Wilmot index (WI), while the lowest root mean square error (RMSE) and mean absolute error (MAE) (Table 4). The values of performance evaluators for all developed models for the four different models, r ranged from -0.59 to 0.99, RMSE (mm h^{-1}) from 0.10 to 44.08, MAE (mm h^{-1}) from 0.08 to 281.43, NSE from -28579.30 to 0.99 and WI ranging f0.00 to 0.99. The Green Ampt, Kostiakov, and Philip models were

Table 4. Performance evaluation of infiltration models for different locations

Models	Performance evaluation				
	r	RMSE (mm h^{-1})	MAE (mm h^{-1})	NSE	WI
Kalyanpur Village					
Green-Ampt	0.95	0.53	0.32	0.89	0.97
Philip	0.96	0.44	0.38	0.93	0.98
Kostiakov	0.99	0.17	0.15	0.95	0.99
Horton	-0.26	40.91	21.06	-646.09	0.00
Akbarpur Village					
Green-Ampt	0.94	0.99	0.38	0.87	0.97
Philip	0.98	0.54	0.44	0.96	0.99
Kostiakov	0.98	0.36	0.29	0.94	0.99
Horton	-0.46	427.11	273.41	-24501.69	0.00
Tira Village					
Green-Ampt	0.99	0.13	0.11	0.99	0.99
Philip	0.98	0.53	0.43	0.96	0.99
Kostiakov	0.98	0.36	0.29	0.93	0.99
Horton	-0.46	441.08	281.42	-26544.65	0.00
Rampura Village					
Green-Ampt	0.99	0.12	0.09	0.99	0.99
Philip	0.98	1.39	1.04	0.23	0.89
Kostiakov	0.99	0.13	0.92	0.97	0.99
Horton	-0.42	61.85	41.92	-1582.64	0.00
Ladaura Village					
Green-Ampt	0.99	0.12	0.11	0.99	0.99
Philip	0.98	0.54	0.45	0.96	0.99
Kostiakov	0.98	1.54	1.45	-0.38	0.71
Horton	-0.43	432.53	272.15	-28579.33	0.00
Mirzapur Village					
Green-Ampt	0.99	0.16	0.14	0.99	0.99
Philip	0.97	1.24	0.95	0.53	0.93
Kostiakov	0.99	0.12	0.11	0.98	0.99
Horton	-0.59	2.03	1.13	-0.26	0.22
Basudeopur Village					
Green-Ampt	0.99	0.10	0.08	0.99	0.99
Philip	0.98	1.06	0.81	0.68	0.95
Kostiakov	0.98	0.24	0.19	0.95	0.98
Horton	-0.49	169.47	113.07	-8284.51	0.00
Birsingpur Village					
Green-Ampt	0.99	0.10	0.08	0.99	0.99
Philip	0.98	0.93	0.73	0.78	0.96
Kostiakov	0.98	0.25	0.20	0.95	0.99
Horton	-0.49	195.22	129.88	-9806.78	0.00
Kabargama Village					
Green-Ampt	0.99	3.16	1.82	-0.47	0.39
Philip	0.98	0.53	0.43	0.96	0.99
Kostiakov	0.98	0.31	0.26	0.94	0.99
Horton	-0.43	416.88	263.02	-26761.71	0.00
Phulhara Village					
Green-Ampt	0.99	0.10	0.08	0.99	0.99
Philip	0.98	0.35	0.29	0.97	0.99
Kostiakov	0.98	0.25	0.20	0.95	0.99
Horton	-0.49	188.15	124.94	-9735.65	0.00

more appropriate than the Horton models. Similar trend was observed by Dashtaki et al (2009). The Green Ampt model was superior at eight villages (Tira, Rampura, Ladaura, Mirzapur, Basudeopur, Birsingpur, Kabargama, and Phulhara villages). In contrast, Kostiakov and Philip's models were d best in Kalyanpur and Akbarpur villages. Meanwhile, Horton's model performs very poorly at all locations. The results reveal that Horton's parameters do not fit the conditions for given locations. This could be because lack of a consistent physical interpretation for their parameters.

The values of coefficients of determination (R^2) for different villages ranged from 0.27 to 0.99. The Green-Ampt model performed superior at Tira, Rampura, Ladaura, Mirzapur, Basudeopur, Birsingpur, Kabargama and Phulhara villages with the highest values of R^2 as 0.99. Considering Kostiakov and Philips model performed outstanding at Kalyanpur and Akbarpur village with R^2 values of 0.97 and 0.96, respectively. The developed models were under-predicted and over-predicted throughout the datasets.

CONCLUSIONS

The present study evaluates infiltration rate at ten locations of Kalyanpur villages. The double ring infiltrometer was used to evaluate the infiltration at given locations. Based on the performance evaluations using suitable indicators, it was observed that the Green Ampt models were suggested at given locations as at eight locations out of ten it was found superior. The Hortons model perform very poorly at given locations.

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Feasibility Study on Using Smartphones via Bluetooth for Commanding Buffalos

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Abstract: Thai water buffalos (*Bubalus bubalis*) or krabue (in Thai) are native animals that play an essential role in the traditional way of life of Thai farmers, especially in farming processes, including tilling soil in preparation for planting, providing manure to be used as fertilizer, and dragging carts to carry rice, among other tasks. To the farmers, therefore, water buffalos are an important part of their team and are even considered to be like their family members. Nowadays, the use of a two-wheel type of tractor is increasingly replacing buffalos because they are more convenient and better able to serve mass production needs. However, when the economic situation changes and the price of oil and the cost of living both increases, farmers return to using buffalos in their farming activities in line with the sufficiency economy theory. Therefore, this research aims to improve the standard of living of Thai farmers by studying the possibility of using modern technology and innovations in the form of smartphones operated via Bluetooth to command the buffalos to move in the desired direction. A prototype system was developed for commanding buffalos to work for farmers. The results show that the buffalos tend to comply with the commands from the developed equipment. However, the equipment still requires further development.

Keywords: Buffalos, Commanding, Smartphones

Water or swamp buffalos are mainly found in East and South Asia and represent 20.51% of the world's total buffalo population (Cruz 2013). Drought-adapted water buffalo provide meat and highly nutritious milk that can be used to make cream, butter, yogurt, and cheese. Knowledge about the water buffalo gives farmers the power to improve the sustainability, efficiency, and profitability of their production (Cruz 2012, Hazem et al 2019). When buffalos produce offspring, they increase the household assets that can be rented out in exchange for either cash or nonfinancial assets and services (Bonnin 2015). In Cambodia, these animals are concentrated in rice-growing areas, with cattle and buffalo predominantly kept to provide power for soil preparation, weeding, harvesting, and transportation as well as to provide manure rather than being bred for meat production (Sokerya et al 2010). Indeed, nearly 80% of farmers raise buffalos as a source of power for work (Sarakul et al 2016). Thai water buffalos can be trained to work in many farm activities such as plowing, raking, or dragging while they can also be ridden as a form of transport. However, the role of water buffalos in farming has been increasingly neglected by the government and even by farmers as they are replaced by two-wheel tractors. In both lowland valleys and highland terraces, two-wheel tractors, known in the Thai language as 'Iron buffalos', are increasingly used for plowing rice fields (Rigg 2003). Studies indicate that two-wheel tractors are relatively cheap to buy and operate as well as being more convenient and efficient for tilling than buffalos. As farmers use ever-increasing amounts of chemical fertilizers, buffalo dung also plays a lesser role in maintaining soil fertility than in the past (Jean-François Rousseau and Janet Sturgeon 2019). Only when farmers are faced with higher costs of living and oil prices are water buffalos considered to be of use again (Table 1).

The of training buffalos for plowing is important. Buffalos can be trained from between 2-3 years old. At this age, the buffalos are beginning to have strong muscles and can pull the plow but can be controlled easily. Before training, buffalos should be strong-looking, with strong legs and hooves. When they walk, the rear foot should cross the front foot at each step. Requires the use of a rope passed through the septum of the buffalo's nose. The rope should be passed indirectly under the ear and tied at the back of the neck with a dead knot at the appropriate tautness (not too tight or too loose). Another rope tied around the neck will be used as a means of controlling the carrying rope. It should not be loose over the front of the ear, as this will loosen the rope and make it difficult to control the buffalo and may be dangerous to the buffalo if it steps on the nose rope. Training the buffalos to know the commands is an important step in the training of Thai water

buffalos (Table 2). The method used in other countries is tail twisting (Gregory et al 2009). The tail and the nose of the bovine are well innervated, and it is recognized from clinical practice that they are sensitive to a range of potentially painful stimuli. The nose rope command is based on the principle of applying pressure to a sensitive part of the buffalo. This makes the buffalo more tractable and more easily led by hand when the nose rope is pulled (Alam et al 2010). For the voice commands used to communicate with the buffalos, they depend on the person doing the training and which local commands are normally used to make the buffalos understand the command. The objective of this feasibility study is to explore the use of smartphones via Bluetooth for commanding buffalos to move in the desired direction. The methods employed for commanding buffalos may also be applicable to other trainable animals with good learning skills. This technology has the potential to replace two-wheel tractors in a rice field with buffaloes.

MATERIAL AND METHODS

The operation system design of the control equipment used to study the feasibility of using a smartphone via a Bluetooth controlled device for commanding buffalos is summarized in Figure 1.

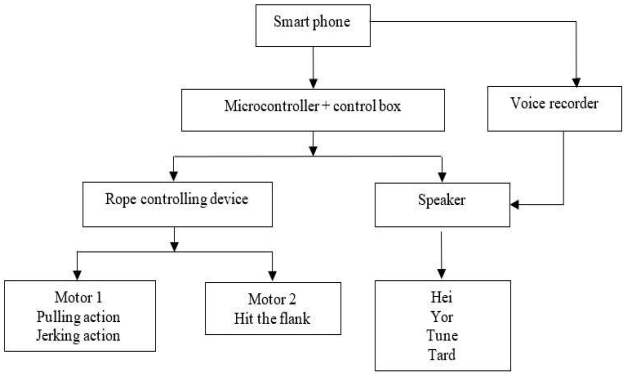

Fig. 1. Schematic diagram of using smartphone via Bluetooth for commanding buffalos

Table 1. Comparison between two-wheel tractors and buffalos (Department of Livestock at Wang Noi District and Non-Formal Education Centre at Wang noi 2016)

Topics	Two-wheel tractor	Buffalo
Price	700 - 1,400 USD*	270 - 500 USD
Lifetime	Main structure 5 -7 Yrs. Engine 8-10 Yrs.	25 - 30 Yrs.
Cost during work	Fuel cost	Nothing
Working hours	8 -10 hrs./day	4 - 6 Hrs./day
Efficiency	0.48 – 0.8 ha/day	0.08 – 0.16 ha/day
When expired	Out of service, sold as scrap metal	Dies, sold as meat
Size of land that can be farmed	Suitable for more than 3.2 ha	Suitable for 0.48 - 1.6 ha
When not using to plow	Used as farm truck, deteriorates, continuously requires expenses for maintenance	Used with cart as farm tuck, can produce baby buffalos
Operator	Strong man	Man, woman, teenager
Waste product from usage	Engine oil makes soil pollution	Produces manure (Shirai and Yokoyama 2014)

* Average 8-14 Hp Price including of engine, main structure and cage wheel

Table 2. Examples of rope and voice commands to buffalo

Action	Wang Noi District, Khon Khen Province (North-east province of Thailand)		Suphanburi Province (Central province of Thailand)	
	Rope	Voice	Rope	Voice
Move forward	A well-trained buffalo may not require the use of a rope and can be controlled by voice commands only.	Pai	The other end of the rope is used to hit the flank of the buffalo	Hei
Stop		Yor	-	Yor
Turning left		Leaw	Pull	Tune
Turning right		Tok	Jerk	Tard
Move backward (When plowing stuck to a stumps)		Hon	Push from the front	-

The smartphone via Bluetooth control device for commanding buffalos consists of 1) software on a smartphone (HTC model Desire C), 2) a control box with microcontroller AT89C2051, 3) voice recording equipment, 4) speakers 15 Watt, 5) a 12 VDC battery, 6) a nose rope, 7) a main structure, 8) a controlling unit for turning the buffalo, and 9) a controlling unit for move forwarding the buffalo (Fig. 2).

When pressing the right arrow icon on the smartphone to make the buffalo turn right, the motor will spin to twitch the rope, and the speaker will play a 'tard' sound, prompting the buffalo to turn right. The twitching mechanism is similar to the crankshaft rotation. When pressing the left arrow icon on the smartphone to make the buffalo turn left, the motor will spin to pull the rope, and the speaker will play a 'tune' sound, prompting the buffalo to turn left. A specific time is set, after which the motor will spin in the opposite direction to release the tow rope in order to maintain the same rope distance. When pressing the up-arrow icon for the buffalo to move forward, the motor that controls the buffalo to move forward will spin like a seesaw; the small iron rod will hit the flank of the buffalo to command it to move forward, and the speaker will play a 'hei' sound, prompting the buffalo to move forward. When pressing the back-arrow icon to go back or to stop the buffalo, the speaker will play a 'yor' sound, prompting the buffalo to stop.

The study was conducted at the Thai Buffalo Conservation Village, Suphan Buri Province. The experiment conditions were as follows: 1. the buffaloes that were used in this experiment had to have been trained beforehand (Table 3). 2. Buffalos participating in the experiment were not equipped with plowing equipment; and 3. Control distance was limited to not more than 10 meters depending on the Bluetooth signal power. The experiment focused on controlling buffalos using voice and nose rope commands, with eight different tests repeated ten times each. The reactions of the buffalos to the commands were recorded, and then the results were compared in percentages. The details of the buffalos used in the experiment are shown in Table 3. The three buffalos used in the experiment named Sao (B1), Peuk (B2), and Suk (B3) were aged 17, 15, and 12 years old, respectively (Fig. 3). These buffalos started being trained using voice and nose rope commands at the age of three. The authors took three days to become familiar with the buffalos before the experiment. The test methodology is shown in Table 4.

RESULTS AND DISCUSSION

The results show that when using nose rope commands only, voice commands only, and nose rope commands

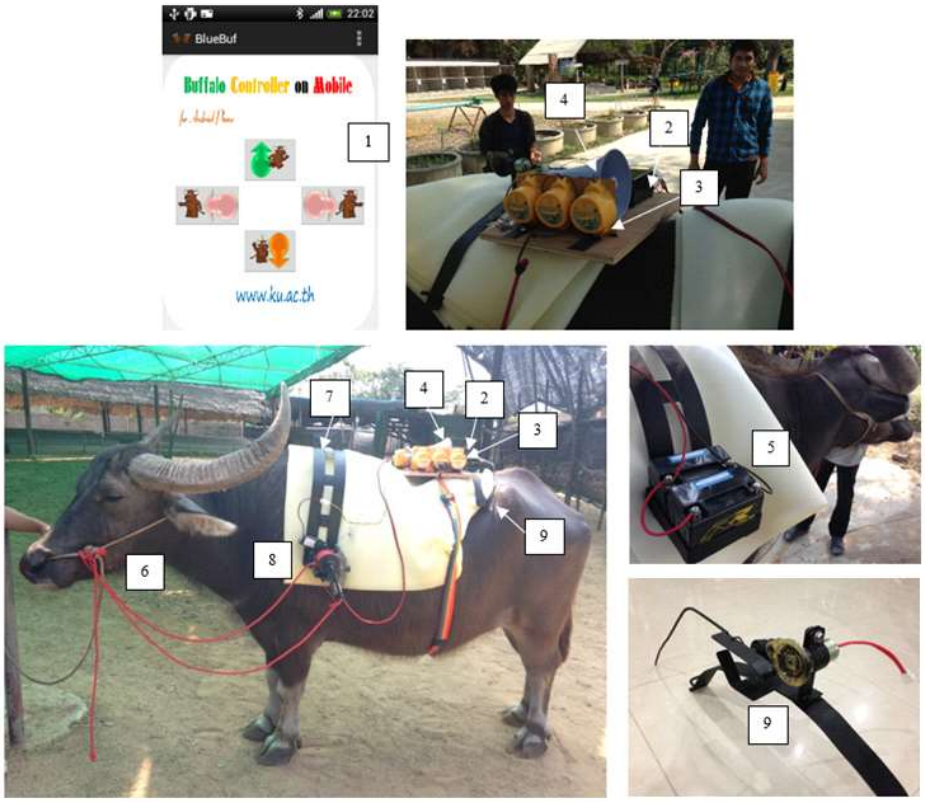

Fig. 2. Smartphone via bluetooth control device for commanding buffalos

together with the voice commands of the buffalos' owners to control the buffalos, all of the buffalos were able to perform 100% of the commands (Table 5). When using the voice of other people (the research team) rather than the owners' to control the buffalo, the average success rate for the commands to go forward and to stop was 73.34%. When testing the effectiveness of the nose rope commands from the developed equipment to control the buffalos, the results show

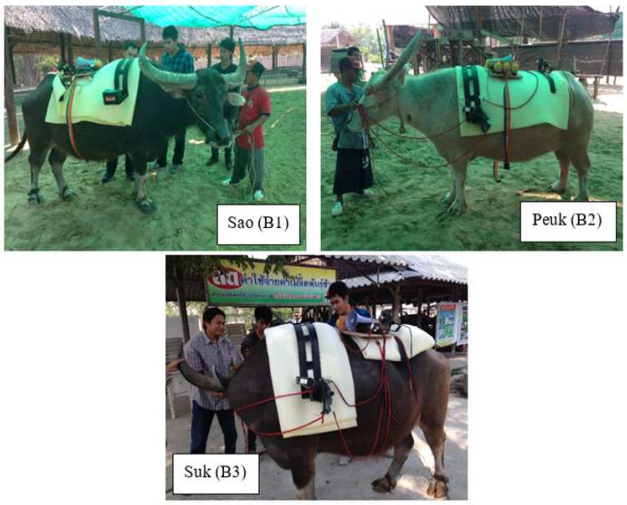

Fig. 3. Buffalos used in this experiment

Table 3. Buffalos used in this experiment

Name	Age (Years)	Trained since (Age)	Habits
B1	17	3	Docile, friendly, fast learner
B2	15	3	Docile, friendly
B3	12	3	Alert, stubborn

Table 4. Methods of buffalo commanding

Test	Methods of buffalo commanding	Operator
1	Testing of nose rope commands to control the buffalo	Buffalo's owner
2	Testing of voice commands to control the buffalo	Buffalo's owner
3	Testing of another person's voice to control the buffalo	The research team's voices after being trained by the buffalo's owner
4	Testing of nose rope commands together with voice commands to control the buffalo	Buffalo's owner
5	Testing of nose rope commands to control the buffalo	The developed equipment
6	Testing of voice commands to control the buffalo	The developed equipment with the owner's recorded voice
7	Testing of voice commands to control the buffalo	The developed equipment with another person's recorded voice (The research team's voices after being trained by the buffalo's owner)
8	Testing of nose rope commands together with voice commands to control the buffalo	The developed equipment with the owner's recorded voice

Table 5. Test results of using smartphone via Bluetooth for commanding buffalos

Test	Compliance with buffalo commands (%)															
	B1				B2				B3				Average			
	Go forward	Stop	Turn left	Turn right	Go forward	Stop	Turn left	Turn right	Go forward	Stop	Turn left	Turn right	Go forward	Stop	Turn left	Turn right
1	100	0	100	100	100	0	100	100	100	0	100	100	100	0	100	100
2	100	100	0	0	100	100	0	0	100	100	0	0	100	100	0	0
3	80	80	0	0	80	80	0	0	60	60	0	0	73.34	73.34	0	0
4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
5	10	0	10	10	20	0	20	20	10	0	10	10	13.34	0	13.34	13.34
6	80	80	0	0	80	80	0	0	80	80	0	0	80	80	0	0
7	50	50	0	0	50	50	0	0	40	40	0	0	46.67	46.67	0	0
8	80	80	0	0	70	70	0	0	60	60	0	0	70	70	0	0

1: Nose rope commands to control the buffalo (tested by the owner), 2: Voice commands to control the buffalo (tested by the owner)
3: Another person's voice commands to control the buffalo (tested by the research team), 4: Nose rope commands together with voice commands to control the buffalo (tested by the owner)
5: Nose rope commands to control the buffalo (tested by the developed equipment), 6: Voice commands to control the buffalo (tested by the developed equipment with the recorded voice of the owner)
7: Voice commands to control the buffalo (tested by the developed equipment with the recorded voice of another person), 8: Nose rope commands together with voice commands to control the buffalo (tested by the developed equipment with the recorded voice of the owner)

that the buffalos were able to comply 13.34% of the time for the commands to turn left and to turn right. The results of using the developed equipment with the recorded voice commands of the owners to control the buffalos revealed that the buffalos were able to comply with the commands 80% of the time for the go forward and the stop commands. Using the developed equipment with the recorded voice commands of other people, rather than the owners, the success rate for the 'go forward' and 'stop' commands was 46.67%. Using the developed equipment with the owners' recorded voice commands, the buffalos were able to comply with the commands 70% of the time for the 'go forward' and 'stop' commands. The buffalos were able to understand the voice commands from their owners' very well, especially the go forward and stop commands (Table 5). The buffalos also understood voice commands when they were made by unfamiliar voices. It is possible that the buffalos are most familiar with go forward (*hei)* and stop (*yor*) voice commands because they hear them frequently, and they are easy to follow. For the turning commands, the buffalos did not obey the commands, whether they were made by their owners or unfamiliar voices. They turned their head to the requested direction but did not move, indicating a degree of understanding. When comparing the buffalos' responses to voice commands made by their owners and those made by unfamiliar voices, the buffalos followed their owners' voice commands better than those made by unfamiliar voices. This is likely because the buffalos are familiar with the voices of their owners. However, the buffalos that took part in the study had been trained and worked for a long time and had likely been handled by many caretakers making it easier for them to get accustomed to other people's voices and comply with commands made by unfamiliar voices as well. When comparing between real voices and the recorded voices played through the speakers, buffalos were better able to follow the real voices than the recorded ones. This may be because the quality of the sound from the speakers is not good enough. It is possible that either the buffalos could not hear the voice commands clearly or they could hear them, but because the recorded voice commands were different from those of their owners and did not follow the commands. However, if the sound's quality is improved, then the results may be as good as those made by real voices.

For the nose rope commands made by the owners the buffalos could comply in 100% of cases for all three commands: go forward, turn left and turn right. This may be because the buffalo's noses had been pierced in the right position, which made it easy to control them, and also the buffalos have been well trained, are highly experienced, and have worked for a long time. Otherwise, the difficulty in commanding the buffalos in this way would be known as “hard nose” behavior. When giving commands to turn left and right, the nose rope was pulled or jerked to stimulate the buffalos, causing them immeasurable pain then and motivating them to follow the commands. In the case of moving forward, a hand or the other end of the nose rope is used to hit the buffalos on their left flank to make them move forward and follow the command. From using only nose rope commands by the developed equipment to control the buffalos to turn left (pulling on the rope), the buffalos complied with the commands to turn left on 13.34% of the cases. This is due to the developed equipment's action of pulling and releasing the nose rope not being the same as when the owner pulls on the rope, resulting in the buffaloes not following the commands. The results of the commands by the developed equipment to turn right (jerking the rope) also produced a 13.34% success rate. For the command to go forward, the developed equipment used a steel bar to hit at the left flank of the buffalos, but it was found that the action may have been too soft due to the buffalos having thick skin. According to Muralidharan and Ramesh (2005), the papillary and reticular layers of the Murrah buffalos hides measured 1.18±0.06 mm and 4.91±0.06 mm, respectively while the thickness of the epidermis of the buffalo's skin was 6.16±0.27 μ which is considerably thicker compared to the skin of a cow or camel (Saffia Kareem Wally Al- Umeri and Nabeel Abd Murad Al- Mamoori 2016). Therefore, it is likely that the buffalos did not feel anything when they were hot gently with the bar and did not follow the commands. In testing the developed equipment, the results of using nose rope commands together with voice commands made by the owner's recorded voice to control the buffalos revealed that the buffalos were able to comply with the go forward and stop commands to a favorable degree (70%). This may be because of the sound of the owner's recorded voice played through the speaker being familiar to the buffalos together with their compliance with the commands to turn left and right for the reasons mentioned above.

CONCLUSION

Right up to the present, Thai water buffalos still play an important role in the agricultural production processes of many smallholder farmers, especially in rural areas. It is possible to control buffalos using a smartphone via Bluetooth to commanding them to move in the desired direction, it is necessary for the buffalos to be trained to use the equipment from a young age to enable them to become familiar with the equipment and follow the commands successfully. This same idea may apply to any animals that can be trained and have good learning skills.

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