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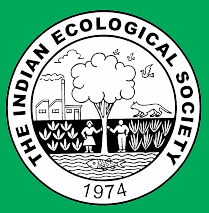

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Genetic Variability Assessment of Growth Traits and Nutrient Uptake of *Populus deltoides* under Punjab Conditions

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Abstract: The present study was conducted on 7-year-old *Populus deltoides* clones for growth, biomass and nutrient uptake characteristics under Punjab conditions at Punjab Agricultural University, Ludhiana which falls under the Central Plain Zone. Observations on total height, diameter at breast height, volume and biomass were recorded, and nutrient uptake was worked out. Significant differences were observed among clones for all the characteristics. The clone FNR-558 was observed as most promising clone for DBH, volume and biomass. The highest value for nitrogen uptake was observed in L-47/88. For phosphorus and potassium uptake was maximum in clone FNR-558. Majority of parameters studied except straightness were less influenced by the environment conditions and thus reflect the variability for the traits in *Populus deltoides* is tightly linked with the genotypic constitution. High heritability (69.80%) coupled with moderate genetic gain (16.57) was observed for volume. Genotypic correlation coefficient higher than phenotypic correlation coefficient revealed the less effect of the environment on the expression of these traits and would be helpful in future breeding programs. FNR-558 recorded highest index score followed by Ranikhet, FNR-544, L-170/88 and L-247/84, therefore showing promising results.

Keywords: *Populus deltoides*, Clones, Growth, Nutrient uptake, Genetic parameters, Correlation, Path analysis, Index score

In India, the term 'poplar' is used synonymously with *Populus deltoides*, an exotic species introduced from North America during the early 1950s and has gained much popularity as commercial timber tree, due to multifarious uses, market potential and fast rate of growth. *P. deltoides* is the main exotic Poplar in India and widely cultivated in the Indo-Gangetic plains of north-western region of India (Kumar and Singh 2012). Poplar grows excellent in soil having >10 % soil porosity, 35% or much less clay content material and pH range in between 6.5-8.0 (Dhillon and Sidhu 2007). In India, the farmers of north-western states adopted the poplar tree for its higher productivity (up to 48 m^3 $ha^{-1}year^{-1}$), short rotation (5-7 years), straight stem and compatibility in agroforestry systems (Dhillon et al 2010a).

Poplar is the major species behind the development of a vibrant plywood industry in north-west India. It is also used to a significant extent in match industry. The waste wood is used for making paper or as fuel. Every year poplar in non-forest area produces 1.20 million m^3 wood for making plywood and is thus saving 43,000 ha natural forests or 13,500 ha forest plantations from felling every year to produce the same quantity of wood. Farmers are earning handsome profits from nursery as well as plantation activities (Tomar and Srivastav 2020). Farmers in Punjab, Haryana, and Uttar Pradesh began growing poplar trees commercially as a means of diversifying their rice-wheat crop rotation which can provide high economic returns compared to the traditional cropping system (Singh et al 2022). The species is propagated by vegetative methods, resulting in intra and inter-specific hybridization.

Commercial poplar plantations in India mainly rely on a few clones, including G-3, G-48 and WSL series, resulting in a narrow genetic base that makes the plantations susceptible to insects and leaf spot diseases (Singh et al 2004). Such limited hereditary base of clonal plantations may pose a huge risk to the long-term productivity and recommendation is to replace 5 to 10% of available clones annually. Accordingly systematic breeding and selection work was started at Punjab Agricultural University since past three decades and many clones were put for field evaluation for commercial cultivation. Different promising clones have been developed by various research organizations in the nation and are being tested in a number of locations to meet the ever-increasing demand for poplar wood as well as farmers' interest in poplar cultivation. Due to limited number of clones present for cultivation under Punjab conditions there might be a chance the few of these clones may become susceptible to various diseases or insect pests which will affect large number of plantations in the region (Dhillon et al 2020). To have diverse number of clones for cultivation and to select high performing clones it is important to evaluate various new clones under these conditions. There is a lack of data on biomass production and nutrient uptake in these poplar clones. This paper reports the clonal variability in growth traits, biomass production in poplar at age of 7 years.

MATERIAL AND METHODS

The research study evaluated twelve clones of *Populus deltoides* under field conditions at Punjab Agricultural University, located central part in Ludhiana (30° 54´ N latitude, 75° 48´ E longitude, and at an altitude of 247 m amsl. The climate in Ludhiana is characterized by hot summers and desiccating winds from April to June, and cold winters with occasional ground frost from December to January. Most of the 760 mm annual average rainfall in the area occurs between July and September. The study was conducted on 7-year-old trees that were established under a randomized block design with three replications and a plot size of 5 trees. The growth parameters like tree height, diameter at breast height, crown length, number of branches per meter of crown length; stem quality traits like clear bole height and straightness; and yield traits like volume and biomass; and nutrients accumulation by trees were recorded. For estimation of volume, trees were converted into commercial logs. The volume of single tree was then calculated by summation of volume of all logs. Biomass of trees was calculated at the time of harvesting by weighing individual logs and branches on a weighing machine and adding them together (kg tree^{-1}).

Nutrient uptake in polar clones was determined by evaluating the nutrient content from different plant parts. For this plant samples were taken from different parts of tree like tree bole, branches and leaves. For determination of N, plant samples were digested with H_2SO_4 and for P and K, these samples were digested with nitric acid and perchloric acid in the ratio of 3:1. Nitrogen Determination was done via Kjeldahl method. Vanadomolybdo phosphoric yellow colour method in a nitric acid system was used to quantify the total phosphorus in plant extracts and potassium using flame photometer's atomizer assembly. Final values of the nutrients which were in percentage were then multiplied with biomass to calculate nutrient uptake per tree. For nutrient uptake per acre by the poplar planted at 5m x 4m spacing (500 trees/ha) the nutrient uptake was calculated as: Nutrient uptake per acre (kg) = Nutrient uptake per tree (kg) × 500 trees per ha.. Statistical analysis was done using CPCS1 software developed by PAU Ludhiana and aassociation studies (Al-Jibouri et al 1958), path analysis (Wright 1921, Dewey and Lu 1959).

RESULTS AND DISCUSSION

There were significant differences among the tested clones for all the growth and yield characteristics (Table 2). Clone FNR-558 had the highest DBH (21.42 cm), which is statistically at par with almost all clones except L-17/92, L-290/84 and L-168/88 had the lowest value (18.80 cm). Seven clones had higher DBH than the overall mean, with FNR-558, Ranikhet, and L-47/88 being the top three. The maximum tree height (17.75 m) was in L-170/88, which was statistically superior to four clones i.e. L-290/84, L-17/92, WSL-29, and L-168/88. The tree volume ranged from 0.180 m^3 to 0.243 m^3 per tree. Four clones recorded higher value for volume than overall mean in order of FNR- 558 > Ranikhet > L-47/88 > FNR-544. The clone FNR-558 and Ranikhet had the highest mean biomass, while L-168/88 had the lowest (Fig. 1). All clones were statistically at par with FNR-558 except L-290/84, L-17/92, L-47/88, and L-168/88 clones. Six clones had a higher biomass than the overall mean, FNR-558followed by Ranikhet, L-47/88, FNR-544, L-170/88, and L-247/84, in that order. This indicates the existence of adequate genetic variability in the experimental material which could be exploited for further recommendation of these clones for commercial cultivation. Understanding the factors that contribute to these variations can aid in selecting suitable clones for specific purposes. Singh et al (2008) assessed the growth traits in 20 *P. deltoides* clones in Punjab and recorded significantly variations.Sidhu and Dhillon (2007), Dhillon et al (2010b, 2013), Otis-Prud'homme et al (2023) and Zhao et al (2013) collectively also indicate significant variations in the growth performance of poplar clones at different ages.

The mean value of clear bole height ranged from 9.50-10.88 m (Table 2). The maximum clear bole height was in cloneFNR-558 followed by L-247/84, whereas minimum clear bole height was in clone FNR-544 (9.50 m). Mean value of crown length and number of branches per meter crown length ranged from 5.25 m (L-168/88) to 8.22 m (FNR-558), and from 4.15 (Ranikhet) to 5.97 (L-48/89). The highest mean value for straightness was in L-247/84 (3.80) followed

Table 1. Description of poplar clones used in the research experiment

Source	Clone
Local selection	FNR-558, FNR-544
Dr Y S P University of Horticulture & Forestry, Nauni	Ranikhet
Uttarakhand State Forest Department, Lalkuan	L-170/88, L-247/84 , L-290/84 ,L-168/88 .L-17/92 ,L-47/88 (Check), L-48/89 (Check)
Wimco Seedling Pvt. Ltd.	WSL-29
Dr Y S P University of Horticulture & Forestry, Nauni	RD-01

by L-48/89 (Check) while the minimum value for straightness was in L-168/88. There were significant variations among all the stem quality parameters among poplar clones except in straightness score. These are the traits are those which are affected by both genetic make-up as well as environmental conditions in which the trees are growing. The clone FNR-558 showed outstanding performance for stem quality traits. Dhillon et al (2013) also observed substantial variations in number of branches, and crown width across 36 poplar clones. Jha (2020) evaluated forty genotypes of poplar for juvenile wood yield and its components, and revealed significant differences.

Significantly differences for nitrogen uptake were observed among the clones which varied from 603.28 kg/ha (L-168/88) to 1471.68 kg/ha (L-47/88). Clone FNR-558 showed the highest mean value for phosphorous (177.68 kg/ha) and potassium (956.7 kg/ha) uptake, while L-17/92 exhibited the lowest (95.4 kg/ha and 613.38 kg/ha, respectively). Nitrogen uptake efficiency varied among the clones, with four clones L-290/84, FNR-544, L-168/88 and L-48/89 demonstrating higher values, and lowest value was in L-47/88 (Fig. 2). Clone L-17/92 registered higher biomass per kg uptake of the phosphorus and potassium. Among different nutrients, uptake of nitrogen was highest among all the poplar clones and was followed by uptake of potassium while phosphorus uptake was the lowest among all three nutrients.

In general, the phenotypic coefficient of variation was higher than the corresponding genotypic coefficient of variation for all traits reflecting the sufficient genetic variations for the traits studied among clones (Table 4). Low genotypic variance was observed in general. A high heritability indicated that much of the variation for a given characteristic observed in the clones is genetic in origin. Very high heritability (>60%) was in crown length, tree height, DBH and CBH, which means that the traits were under the strong influence of additive gene action and selection would be quite effective, whereas lowest heritability was recorded for straightness (28.29%). In the current study, the trend of genetic advance as per cent of mean shows a huge scope for genetic improvement in *P. deltoides.* The moderate genetic gain (17.68%) was recorded for crown length followed by volume (16.57%). This indicates that selection should be based on volume. Similar finding were also reported in Poplar by Dhillon et al (2010b) and Liu et al (2023), Kumar and

Table 3. Variation in nutrient uptake by the clones of *Populus deltoides*

Clone	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)
FNR-558	1307.95	177.68	956.70
Ranikhet	1362.03	138.43	936.48
L-170/88	992.18	129.18	797.23
L-247/84	1096.20	125.13	791.35
L-290/84	631.03	118.25	697.10
WSL-29	1034.40	142.78	751.95
FNR-544	743.93	122.88	838.58
RD-01	988.45	130.68	765.75
L-168/88	603.28	107.23	626.00
L-17/92	1053.13	95.40	613.38
L-47/88 (Check)	1471.68	119.70	888.85
L-48/89 (Check)	742.50	117.43	682.68
CD (p=0.05)	27.01	1.61	10.74

Table 2. Variation in growth and stem quality traits among 12 clones of *Populus deltoides* under field conditions (Age 7 year)

Clone	Tree height (m)	Diameter at breast height (cm)	Crown length (m)	Number of branches per meter crown length	Clear bole height (m)	Volume (m^3 $tree^{-1}$)
FNR-558	17.44	21.42	6.57	5.86	10.88	0.243
Ranikhet	17.27	21.39	7.14	4.15	10.12	0.240
L-170/88	17.75	20.47	7.23	5.56	10.53	0.210
L-247/84	17.61	20.26	6.90	5.71	10.71	0.207
L-290/84	16.75	19.14	6.68	5.94	10.07	0.180
WSL-29	16.53	20.24	6.25	5.85	10.28	0.207
FNR-544	17.72	20.49	8.22	5.92	9.50	0.213
RD-01	16.94	20.17	7.05	4.98	9.89	0.207
L-168/88	14.92	18.80	5.25	5.45	9.67	0.170
L-17/92	16.47	19.64	6.77	5.18	9.71	0.190
L-47/88 (Check)	17.03	20.63	6.69	4.46	10.33	0.220
L-48/89 (Check)	17.08	20.01	6.54	5.97	10.54	0.203
CD (p=0.05)	0.96	1.44	1.13	1.03	0.61	0.040

Dhillon (2016) and Meena et al (2014) indicated that selection *Eucalyptus*and *Melia*should be based on volume rather than tree height, clear bole height and straightness as they have low genetic gain.

The genotypic correlation coefficient values were higher than corresponding phenotypic values for almost all the traits indicating the less effect of environment and true representation of genotype by phenotype (Table 5, 6). Majority of growth traits had significant and positive correlation. Volume showed very strong positive association with the DBH (g=1.003, p=0.984), whereas, negative and moderate association with the number of branches per meter crown length and a weak non-significant association with straightness. The DBH (1.395) had the most direct and positive effect on volume followed by tree height (1.091) at genotypic level, while, 0.964 at phenotypic level (Table 7, 8). In similar studies Jha (2012) and Parthiban et al (2017), reported high positive direct effect of DBH on volume and negative direct effect of tree height on volume.

AUTHORS CONTRIBUTION

Divyanshu Sharma involved in planning, data collection and analysis. GPS Dhillon planned the study, planted the trial and analysed the data. Ashok Kumar Dhakad involved in analysis of data. Baljit Singh helped in collection of soil samples and laboratory analysis of wood and leaf samples.

Table 4. Genetic parameters of variation in poplar clones

Parameter	GCV (%)	PCV (%)	Heritability (%)	GA	GAM (%)
Volume (m^3tree^{-1})	9.63	11.53	69.80	0.03	16.57
DBH (cm)	3.62	4.29	71.41	1.28	6.30
Tree height (m)	4.36	4.97	76.93	1.34	7.88
Clear bole (m)	4.03	4.76	71.78	0.72	7.03
Crown length (m)	9.73	11.04	77.76	1.20	17.68
Branches per meter crown length	9.70	13.85	48.99	0.76	13.98

Table 5. Genotypic correlation coefficient among different characters of *Populus deltoides*

Genotypic correlations	Volume (m^3 $tree^{-1}$)	DBH (cm)	TH (m)	CBH (m)	CL (m)
DBH (cm)	1.003				
Tree height (m)	0.723	0.782			
Clear bole (m)	0.546	0.548	0.494		
Crown length (m)	0.496	0.549	0.869	-0.080	
Branches per meter crown length	-0.406	-0.398	0.087	0.241	-0.060

DBH: Diameter at breast height, TH: Tree height, CBH: Clear bole height, CL: Crown length

Table 6. Phenotypic correlation coefficient among different characters of *Populus deltoides*

Genotypic correlations	Volume (m^3 $tree^{-1}$)	DBH (cm)	TH (m)	CBH (m)	CL (m)
DBH (cm)	0.984**				
Tree height (m)	0.627**	0.624**			
Clear bole (m)	0.419*	0.397*	0.428**		
Crown length (m)	0.401*	0.430**	0.769**	-0.143	
Branches per meter crown length	-0.255	-0.252	0.00	0.094	-0.035

Abbreviation See Table 5 for details

Table 7. Direct and indirect effect of all the independent components on volume using genotypic correlations

Path using genotypic correlations	DBH (cm)	TH (m)	CBH (m)	CL (m)	NOB	Genotypic correlation with volume
DBH (cm)	1.395	-0.012	-0.154	-0.146	-0.080	1.003
Tree height (m)	1.091	-0.015	-0.138	-0.232	0.018	0.723
Clear bole (m)	1.091	-0.015	-0.138	-0.232	0.018	0.546
Crown length (m)	0.765	-0.013	0.022	-0.266	-0.012	0.496
NOB	-0.555	-0.001	-0.068	0.016	0.202	-0.406

Genotypic residual effect = -0.020 Abbreviation See Table 5 for details

Table 8. Direct and indirect effect of all the independent components on volume using phenotypic correlations

Path using genotypic correlations	DBH (cm)	TH (m)	CBH (m)	CL (m)	NOB	Genotypic correlation with volume
DBH (cm)	0.964	0.093	-0.018	-0.058	0.003	0.984**
Tree height (m)	0.601	0.149	-0.019	-0.104	0.000	0.627**
Clear bole (m)	0.383	0.064	-0.045	0.019	-0.001	0.419*
Crown length (m)	0.414	0.114	0.006	-0.135	0.000	0.401*
NOB	-0.243	0.001	-0.004	0.005	-0.013	-0.255

Phenotypic residual effect = -0.026 Abbreviation See Table 5 for details

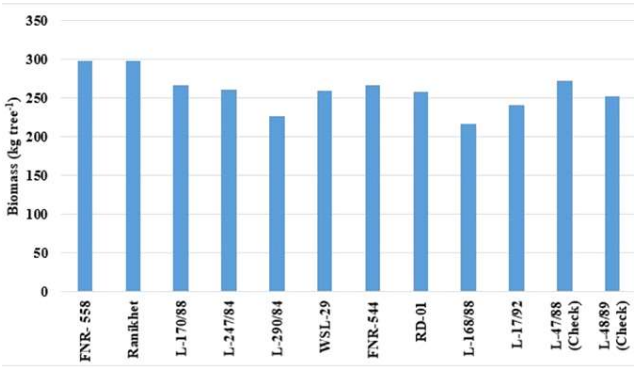

Fig. 1. Variation in biomass (kg tree^{-1}) in clones of *Populus deltoides*

CONCLUSION

The present research indicated noteworthy variations among the poplar clones concerning their growth, allocation of biomass, and nutrient absorption. The research underscores the significance of assessing both genotypic and phenotypic variations among different clones to pinpoint the most promising performers. These outcomes showed practical implications to choose out the best performing clone for commercial plantations in the Punjab state.

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Spatio-Temporal Changes of Water Bodies using Spectral Indices in AABR, Chhattisgarh, Central India

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Abstract**:** The possibility of an ecological imbalance in forests has been pointed up because of the decreasing amount of water source in a forested area**.** Central Indian land receives an abundant but uneven spatiotemporal distribution of rainfall and has evident seasonal water shortages. Remote sensing and GIS techniques are employed for locating and monitoring water bodies, intended to highlight spatio-temporal change patterns of surface water bodies in the protected region of Achanakmar-Amarkantak Biosphere Reserve (AABR) from 2000 to 2020. However, Multi-temporal Landsat satellite data is thoroughly examined through the application of a spectral water indexing method. This method involves leveraging specific spectral bands Near infrared (NIR) and Shortwave infrared (SWIR) that are sensitive to the presence of water, allowing for the precise identification and mapping of water bodies over the study time periods. In study used water indices, Normalized Difference Water Index (NDWI), and Modified Normalized Difference Water Index (MNDWI) to provide significant results for extracting surface water bodies and finding out spatio-temporal changes patterns of the water bodies. The NDWI was employed for assessing the spatial extent of water bodies in the year 2000, revealing a water area of 7.0 km² during pre-monsoon and 32.4 km² for post-monsoon periods, while in 2020, the water area was measured at 22.0 km² in the pre-monsoon season and 50.9 km² in the post-monsoon season. Additionally, MNDWI) was utilized to estimate surface water body extent, indicating a water area of 8.3 km² in the pre-monsoon season and 42.1 km² in the post-monsoon season for the year 2000. In 2020, the water area was measured at 27.0 km² in the pre-monsoon season and 52.3 km² in the post-monsoon season. The monitoring of the AABR is imperative for detecting changes in the area of its surface water bodies that have transpired in recent years. This approach proves highly effective for monitoring and analyzing spatio-temporal variations in water bodies, significantly enhancing our comprehension of landscape dynamics and environmental changes.

Keywords: NDWI, MNDWI, AABR, Geoinformatics, Water bodies, Spectral indices

Water is crucial to the creation of life and the development of human civilization (Falkenmark 2020, Bulavin et al 2020). The water bodies on the surface of the earth have seen significant changes as a consequence of the changing global climate and increased human activities (Tao et al 2011, Yang et al 2015). However freshwater represents only 3% of existing water on the planet, of which 0.3% is available for humans (McDonald et al 2011). On Earth, there are various forms of water, including surface water, groundwater, aquifers, coastal water, and inland water (Oki 2020). Water security and accessibility are important factors for both living organisms and natural ecosystems worldwide (Haddeland et al 2014, Gril et al 2019, Krause et al 2020). Therefore, modern techniques of remote sensing and geographic information systems facilitate the detection and monitoring of water bodies in various regions of the world without making direct contact (Lasaponara et al 2012, Opolot 2013). The signature radiation of each object on the Earth's surface that distinguishes it from others is known as the reflectance band. Remote sensing and geographic information systems employ reflectance bands to analyze the geographic components (Pekel et al 2016, Donchyts et al 2016). The optical sensor and the microwave sensor can be utilized to measure surface water (Watts et al 2012, Schroeder et al 20015, Huang et al 2016). Microwave sensors have the ability to penetrate cloud coverage and certain vegetation coverage due to their usage of long-wavelength radiation (Shrestha et al 2019). There are many natural and man-made reasons, surface water bodies are dynamic in nature and fluctuate in size, shape, appearance, and flow over time (Karpatne et al 2016, Pekel et al 2016). Optical sensors have been widely used in this field due to high data availability, as well as suitable spatial and temporal resolutions (Bhavsar 1984, Huang et al 2015). Normalized difference vegetation index (NDVI) categorizes floods and surface water (Fu et al 2015). Normalized difference water index (NDWI) makes use of reflected near-infrared radiation and visible green light to enhance the presence of such features while eliminating the presence of soil and terrestrial vegetation features (Xu et al 2006). There was extensive usage in the first ten years of the twenty-first century (Nandi et al 2018, Wang et al 2020, Li et al 2022), and modified normalized difference water index

(MNDWI) have been the most useful indices to identify waterbodies and their surface-water spread over the years (Acharya et al 2006). Many researchers have reported the use of NDWI and MNDWI for surface water monitoring (Du et al 2012, Gautam et al 2015, Buma et al 2018, Sekertekin et al 2018, Masocha et al 2018, Ali et al 2019, Bhangale et al 2020, Rad et al 2021, Dastour et al 2022). Remote sensing has developed techniques to change spatio-temporal attributes in georeferenced imagery for extraction of water pixels (Wadhwa et al 2018). Normalized Difference Water Index (NDWI) was applied to classify land and water components from satellite images for automatically extracting the coastline of Diu Island, India (Pham et al 2018). Water body extraction is an important undertaking in different fields. This paper detected the spatiotemporal changes in water bodies in AABR.

MATERIAL AND METHODS

Study area: Achanakmar-Amarkantak biosphere reserve is named after Achanakmar forest village and Amarkantak, from where the rivers Narmada, Johilla, and Sone emerge. Achanakmar-Amarkantak Biosphere Reserve was declared a Biosphere Reserve (BR) by the Government of India in 2005. It falls in tropical dry deciduous forest biomes. Vegetation is generally tropical moist deciduous forests and tropical dry deciduous forests with grassland areas. It lies between latitude 22° 15'N to 21° 58'N and longitude 81° 25'E to 82° 5'E. The total geographical area of AABR is 3835.51 km^2. hosting about 418 villages and 436128 tribal populations inside the AABR (Roychoudhury et al 2020). Daily maximum temperature ranges from 10 °C to 39 °C depending upon season and rainfall. The Biosphere Reserve spreads over 3835.51 sq. km (2610.53 sq. km in Chhattisgarh and 1224.94 sq. km in Madhya Pradesh).

Data description: For the analysis of surface water of the Achanakmar-Amarkantak biosphere reserve (AABR), GEE a web-based cloud computing platform that provides over 11 petabytes of earth observation data was used. GEE offers various advantages-access to the large volume of processed remote sensing image data and dedicated cloud storage; simple and rapid programming and graphic interface and the possibility for assessing surface water dynamics at the planetary scale for a prolonged period. Landsat 5, 7, and 8 with 30 m resolution data were acquired in the pre-monsoon and post-monsoon seasons for the periods 2000, 2010, and 2020 in the study area following the United States Geological Survey (USGS) (Table 1). Five Landsat 5 Thematic Mapper (TM), two Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and eight Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensors (TIRS) data of pre-monsoon seasons and post-monsoon seasons were freely obtained from the GEE.

Normalized difference water index (NDWI): The normalized difference water index (NDWI) is a new method that defines the features of open water and enhances its presence and visibility in remotely sensed digital images (Li et al 2013, Gao 1996). NDWI method uses reflected radiation in the visible green light and near-infrared bands as shown in eq. 1 (Mcfeeters 1996):

NDWI = (Green – NIR)/ (Green + NIR).....(eq.1)

Where NIR is Near-infrared, NDWI value ranges from -1.0 to 1.0. The positive values represent water area whereas the negative values represent non-water lands (Mcfeeters 1996).

Modified normalized differences water index (MNDWI): The MNDWI technique is almost similar to NDWI with only one exception of using a middle infrared band instead of a near-infrared band. This is simply a masking procedure that separates the land. Primarily, it is used for the removal of built-up land noise. In the MNDWI method, the water areas possess higher pixel values as compared to urban or vegetation areas with lower pixel values. Therefore, it delineates the water class from other classes. This method can also efficiently eliminate shadow noise from the water data without involving advanced procedures (Han 2005). The replacement of near-infrared band in NDWI with visible green light and middle infrared bands (MIR) in MNDWI occurs as shown in eq. 2 (Xu 2006):

MNDWI = (Green – MIR)/ (Green + MIR).....(eq.2)

RESULTS AND DISCUSSION

The images given below, which was acquired from the field changes in the AABR from (Fig. 2a-c) pre-monsoon (may) and (Fig. 2d-f) post-monsoon (November) in 2023. The water indices revealed fluctuating and variable threshold values according to the type of water indices and time intervals (Mashagbah et al 2021). The water pixels are known to have positive values whereas other land cover areas exhibit zero or lower values (Yang et al 2017). The NDWI and MNDWI-based water threshold values were observed to be generally greater than 0.3.

Water bodies change analysis based on NDWI: NDWI index is used to emphasize the reflectance of water by using a green band, and suppress the low reflectance of NIR by water features. NDWI indices on pre-monsoon ETM+ (year 2000) recorded water area of 7.0 Km^2 and land area of 3935 Km^2. Similarly in post-monsoon water area is 32.4 Km^2 and the land area is 3909.6 Km^2. In 2010 TM images water area of 12.3 km^2 and land area is 3929.6 km^2 (Table 2, Fig. 3). Similarly in post-monsoon water area is 27 km^2 and the land

Table 1. Specifications of satellite data used in the present study

Year	Satellite/Sensor	Spectral bands(μm)	Spatial resolution (m)	Source of data
2000	Landsat-7 ETM+	Band 1: 0.452–0.514	30	USGS Website
		Band 2: 0.519–0.601	30	
		Band 3: 0.631–0.692	30	
		Band 4: 0.772–0.898	30	
		Band 5: 1.547–1.748	30	
		Band 6: 10.31–12.36	30	
		Band 7: 2.065–2.346	30	
		Band 8: 0.515–0.896	15	
2010	Landsat-5 TM	Band 1: 0.452-0.518	30	USGS Website
		Band 2: 0.528-0.609	30	
		Band 3: 0.626-0.693	30	
		Band 4: 0.776-0.904	30	
		Band 5: 1.567-1.784	30	
		Band 6: 10.40-12.50	120	
		Band 7: 2.097-2.349	30	
2020	Landsat- 8 OLI	Band 1: 0.43-0.45	30	USGS Website
		Band 2: 0.45-0.51	30	
		Band 3: 0.53-0.59	30	
		Band 4: 0.64-0.67	30	
		Band 5: 0.85-0.88	30	
		Band 6: 1.57-1.65	30	
		Band 7: 2.11-2.29	30	
		Band 8: 0.50-0.68	15	
		Band 9: 1.36-1.38	30	
2000-2020	IMD Precipitation	1.0 x 1.0 degree (Grided data)		IMD

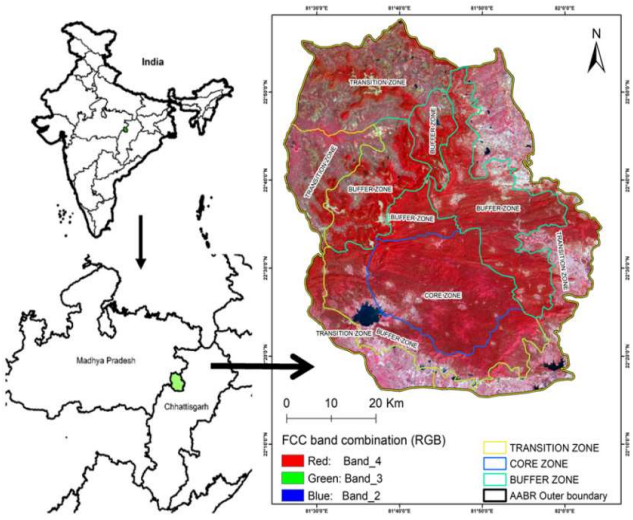

Fig. 1. Location of the study area, a standard false color composite (FCC) of Landsat- 8 OLI

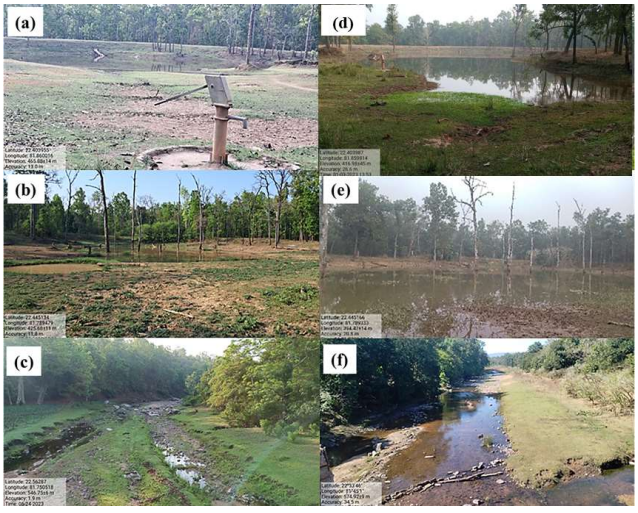

Fig. 2. Delineation of water bodies in AABR, (a-c) pre-monsoon (May), and (d-f) post-monsoon (November) in the AABR range

area is 3915 km^2. The examination of Operational Land Imager (OLI) images in 2020 unravels increase in water area, with NDWI revealing a water extent of 22 km^2 during the pre-monsoon season and land area is 3919.9 km^2. This substantial rise in water area likely signifies shifts in hydrological patterns, land use changes, or other environmental factors (Wagner et al 2016). The post-monsoon phase of 2020 continues to demonstrate this trend, with a water area of 50.9 Km^2 and the land area is 38893 km2 (Table 2). Comparing these findings across the years, study area's water bodies exhibit variability in response to annual climatic fluctuations. The post-monsoon periods consistently portray elevated water areas, indicative of the pivotal role played by the monsoonal rains in replenishing and expanding surface water bodies. Additionally, the varying magnitudes of water extent across different years underscore the dynamic nature of water systems, which can be influenced by a multitude of factors including precipitation patterns, land use changes, and anthropogenic activities (Van der Esch et al 2017). The NDWI-based assessments provide valuable information for understanding the interplay between climatic variations and surface water dynamics (Table 2, Fig. 3). These results contribute to a broader comprehension of hydrological processes within the study area and serve as a foundation for informed water resource management and environmental planning (Badham et al 2019). The consistency of NDWI in detecting water bodies across the years, despite their differing magnitudes, attests to the index's effectiveness in capturing water-related changes. However, it's important to note that further investigations into the underlying drivers of these changes, beyond the scope of this study, could shed additional light on the complex interactions shaping the observed patterns.

Water bodies change analysis based on MNDWI: Examining the results from the pre-monsoon period of 2000, the MNDWI-based assessment reveals a water area of approximately 8.3 km^2. This finding underscores the sensitivity of the MNDWI index in detecting even relatively modest water extents during periods of potentially lower water availability. The associated land area of 3933.7 km^2 provides context, illustrating the distribution of terrestrial features within the study area during this specific time frame. Transitioning to the post-monsoon phase of 2000, the MNDWI analysis shows a substantial expansion of water coverage, spanning about 42.1 km^2. This considerable increase underscores the considerable impact of seasonal variations, particularly monsoonal precipitation, on the augmentation of surface water bodies. The concurrent decrease in land area to 3899.8 km^2 further emphasizes the dynamic nature of these changes, wherein the land-water balance responds to meteorological influences. Turning to the year 2010 and the Landsat Thematic Mapper (TM) images, the pre-monsoon MNDWI assessment discloses a water area of approximately 14.4 km^2. This observation reaffirms the MNDWI's ability to capture water bodies, even during seasons with potentially less pronounced water features. The associated land area of 3927.6 km^2 offers a comprehensive view of the land-water distribution, indicating the composition of the study area during the pre-monsoon phase of 2010. The post-monsoon phase of 2010

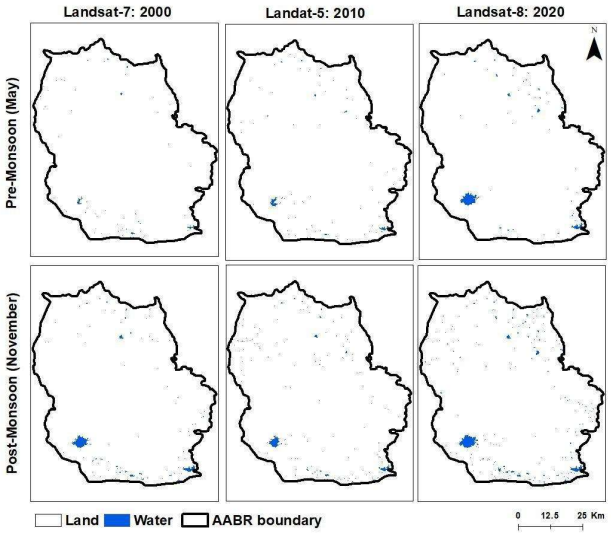

Fig. 3. Water bodies change pattern based on NDWI of Landsat data Pre and Post Monsoon (2000-2020)

Table 2. Water changes status based on NDWI (area in Km^2)

Year	Class	Pre-Monsoon	Post-Monsoon	Change (post-pre)
2000	Land	3935	3909.6	-25.4
	Water	7	32.4	25.4
2010	Land	3929.6	3915	-14.6
	Water	12.3	27	14.7
2020	Land	3919.9	3889.3	-30.6
	Water	22	50.9	28.9

underscores the index's responsiveness to seasonal shifts, showcasing a water area of 25.3 km^2 and a corresponding land area of 3916.7 km^2. The observed changes in water and land extent reveal the intricate interplay between hydrological variations and terrestrial elements. Fast-forwarding to the year 2020 and the use of Operational Land Imager (OLI) images, the pre-monsoon MNDWI assessment demonstrates a considerable water area of 27.0 km^2, suggesting pronounced water features during this time frame. The associated land area of 3915.0 km^2 provides context to the water extent, signifying the intricate relationship between land and water elements. Continuing the trend, the post-monsoon period of 2020 maintains the observed pattern, registering a water area of 52.3 km^2 and a corresponding land area of 3889.3 km^2 (Table 3). These consistent findings across various years underscore the reliability of MNDWI in capturing and quantifying changes in surface water dynamics.

Precipitation trends over water bodies: AABR has a tropical monsoon climate characterized by hot, humid, rainy summer, because of its proximity to the Tropic of Cancer and its dependence on the monsoons for rains. The monsoon season is from late June to October and winter. The annual average minimum, mean, and maximum temperatures in the area are 22˚C, 26˚C, and 33˚C, respectively. In the wet season, rainfall varies greatly and is influenced by local and regional hydroclimatic conditions. The area receives rainfall from South-West Monsoon. A broad variation of precipitation intensity characterizes the hot and muggy summer season. Local long-term rainfall varies greatly from month to month within a year. However, specific months show a wide range of rainfall variation across different years (Table 4). Overall, the hydrologic regime in the area is divided into dry (November through May) and wet seasons (June through October) (Fig. 5a, b). The wet season receives around 75% of the annual

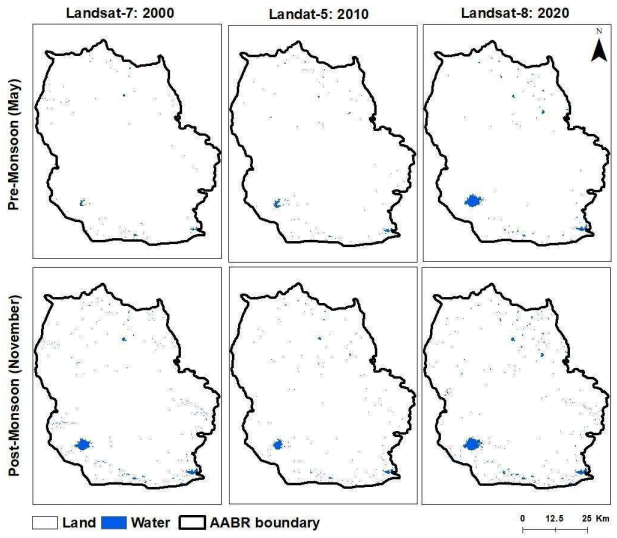

Fig. 4. Water bodies change pattern based on MNDWI of Landsat data Pre and Post Monsoon (2000-2020)

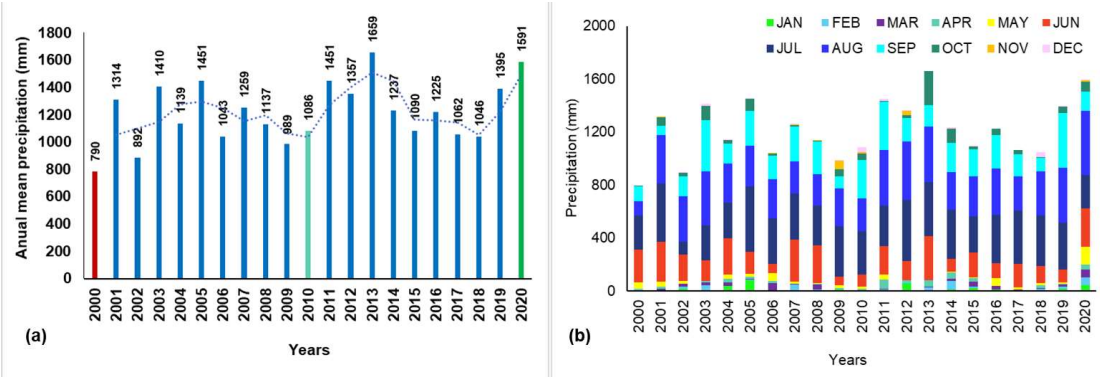

Fig. 5. (a) 20-year precipitation trends (Red: low precipitation in 2000, Yellow: moderate precipitation in 2010, and high precipitation in 2020) (b) monthly precipitation trends over water bodies in the AABR region

Table 3. Water changes status based on MNDWI (Area in Km^2)

Year	Class	Pre-Monsoon	Post-Monsoon	Change (post-pre)
2000	Land	3933.7	3899.8	-33.9
	Water	8.3	42.1	33.8
2010	Land	3927.6	3916.7	-10.9
	Water	14.4	25.3	10.9
2020	Land	3915	3888.0	-27
	Water	27	52.3	25.3

Table 4. Twenty years mean precipitation of AABR region

Month/ Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
2000	4	11	0	0	52	242	261	106	114	0	0	0	790
2001	3	0	13	19	34	301	440	364	74	66	1	0	1314
2002	17	12	22	0	25	196	97	343	151	26	0	0	892
2003	1	40	25	10	0	153	263	409	385	111	0	13	1410
2004	40	0	22	28	32	274	270	294	150	25	1	1	1139
2005	83	1	7	18	22	165	493	306	266	88	0	2	1451
2006	0	0	59	16	60	67	348	293	175	20	5	0	1043
2007	0	47	6	2	17	316	347	240	262	13	8	0	1259
2008	5	7	35	6	4	287	299	239	244	9	3	0	1137
2009	13	0	0	9	23	63	381	284	93	55	61	8	989
2010	7	0	0	9	13	96	328	243	291	50	14	37	1086
2011	0	10	4	70	41	214	305	417	368	2	0	19	1451
2012	58	10	0	11	3	143	464	438	181	20	30	0	1357
2013	0	25	9	45	1	332	409	422	160	257	0	0	1659
2014	8	64	21	46	7	95	372	283	218	107	0	15	1237
2015	24	7	38	27	4	191	275	296	207	18	0	2	1090
2016	10	3	25	2	54	116	366	347	252	49	0	0	1225
2017	2	5	4	0	15	177	405	255	167	31	0	0	1062
2018	0	19	1	21	19	130	381	331	104	3	0	38	1046
2019	17	12	20	5	8	97	357	411	413	48	0	7	1395
2020	41	61	61	35	132	294	250	484	142	77	11	1	1591

precipitation, which is brought on by tropical monsoon systems and convective rains.

Rainfall distribution with a long-term total annual average of 790 mm in 2000, and 1086 in 2010 and it has increased to 1591 mm in 2020 (Table 4). Thematic maps of pre-monsoon and post-monsoon **(**Fig. 3, 4) are correlated with rainfall. The water spread after the monsoon is larger as a result of the increased water release from the Maniyari River and Khudia Dams, as well as rains from the region below the dams through Feeder Rivers.

CONCLUSION

The surface water area in AABR was examined using geographic information systems and remote sensing methods to determine changes over time. The establishment of threshold values has emerged as a pivotal technique for delineating water bodies, offering a dynamic framework that adapts to the evolving nature of the region's hydroclimatic conditions. This adaptability has been demonstrated vividly through the varying threshold values observed across different time periods and in relation to the specific water indices employed. These nuanced threshold variations, in conjunction with the machine learning algorithm employed, have facilitated a robust estimation of surface water spread across the years 2000, 2010, and 2020, as derived from the Google Earth Engine (GEE). Water bodies have grown and expanded between 2000 and 2020, however, there is still a need for conserving water for the animals in certain areas. The findings of this study reverberate with implications for environmental management and conservation efforts.

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Phytosociology of Important Non-Timber Forest Product Woody Species in Western Himalaya

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***Abstract*:** The region of the Indian Himalaya is rich in NTFPs that serve a variety of purposes and satisfy the needs of rural residents. The current study was conducted in the Lansdowne Forest division of Pauri Garhwal in western Himalaya. A total of 28 trees and 17 shrub species were reported during field survey. These plant species were also categorized on the basis of their utilization pattern by local people from secondary literature. This study reveals that the species with the highest total basal cover in this region for tree species was *Shorea robusta* (9,3082.04), while *Albizia lebbeck* had the lowest (134.55 and for shrub species the highest was found in *Murraya koenigii* (4.71/25m^2) and the lowest was found in *Woodfordia fruticosa* (0.07/25m^2). The species with the highest frequency among trees was *Shorea robusta* (47.50%) and with the lowest frequency was *Aegle marmelos* (2.50%), followed by *Albizia lebbeck* (2.50%), *Anogeissus latifolia* (2.50%), and *Bombax ceiba* (2.50%) respectively, while the species with the highest frequency among shrubs was *Lantana camara* (45%) and with the lowest frequency was *Carissa opaca* (2.50%) followed by *Cestrum aurantiacum* (2.50%) and *Glycosmis pentaphylla* (2.50%), respectively. *Shorea robusta* had the highest density (101.88 ha^{-1}), while *Aegle marmelos* lowest (0.63 ha^{-1}), followed by *Albizia lebbeck* (0.63 ha^{-1}) and *Bombax ceiba* (0.63 ha^{-1}), respectively. However, for shrub, *Eupatorium adenophorum* had the highest density (2.0/ 25m^2), while *Carissa opaca* had the lowest (0.05/25m^2). The tree with the highest importance value index was *Shorea robusta* (59.13), and the lowest was *Albizia lebbeck* (1.83). The shrub the highest importance value index was *Lantana camara* (49.36) and *Glycosmis pentaphylla* had the lowest (1.43).

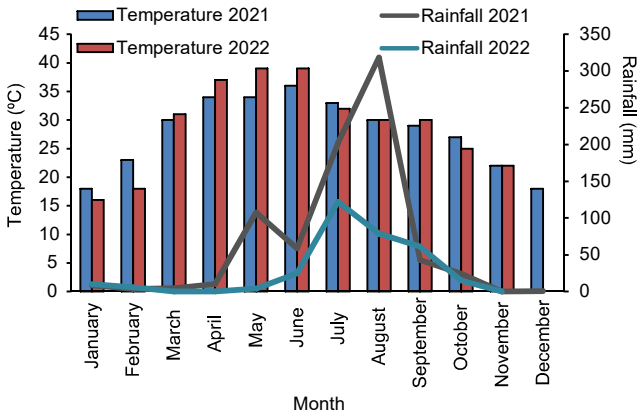
***Keywords*:** Non timber forest products, Western Himalaya, Diversity, Medicinal importance

The Himalayan region is well known for diversification of 5000 plant species (Rao 1994). Whereas nearly 50% of all blooming plants in India, in which 30% blooming plants are indigenous to the Himalayan region, are found there. In the Himalayan region, there are more than 816 tree species, 675 edible plants, and almost 1743 different medicinal plants have been documented by various authors (Samant et al 1998, Thakur et al 2005, 2017). Threats to biological diversity, conservation and utilization pattern of plant species in the Himalayan region might have a significant positive economic impact on the local population and help foster sustainable development (Khoshoo 1992, Dhar 1997). The sustainable utilization of non-timber forest products (NTFPs) is more important in the Himalayan region, in which a large proportion of the rural population relies on forests to meet their basic needs Joshi et al (2018). NTFPs contribute significantly to livelihoods dependency of local people and diverse range of plants products are source of food, nutrition, fodder, fiber, medicine, dye, and a variety of other uses that meet household needs and generate profitable revenue (Sundriyal and Sundriyal 2004, Saxena 2003). The sale of forest products is estimated to provide 10-50% of household income in many local communities (Olsen et al 1997). As a result, numerous development organizations and environmental protection groups have promoted the significance use as goods with reference to promote forest conservation and reducing rural scarcity (Marshall and Schreckenberg 2003). A wide variety of NTFPs have been found in the Himalaya region due to ecological diversity, community structure and their distribution in which certain NTFPs have been used for significant cultural significance, sources of food and building materials, and serve in health care systems (Pradhan et al 2008, Thakur et al 2007). However, the importance of wild edible plants to food security and economic generation has been overlooked (Uprety et al 2012). Therefore, the objectives of this study are to identify NTFPs bearing species and study their diversity, abundance, and density in Western Himalaya, and assessment of their utilization pattern.

MATERIAL AND METHODS

Location and climate: The present study was carried out in Lansdowne Forest Division in Pauri district of Western Himalaya. The study area is located between 29^{0}43' 58.54" N - 29^{0}50' 05.93" N to 78^{0}31' 54.80"E- 78^{0}91' 38.81" E having an altitude from 350-1550 msl., A total of forty quadrate were

laid to determine the community structure and species composition in the study area. The study area comprises deciduous Sal mixed forest (5/B/C2) at lower altitude and lower Shivalik chir pine forest (9/C1a) at upper altitude.



Vegetation sampling and analysis: For phyto-sociological analysis a quadrate size of 20 x 20 m for tree and 5 x 5 m for shrub species were laid randomly from January 2021 to November 2022 by using 20 x 20 m plot for trees. Each plot was sub divided in to 5 x 5 m sample plot for recording shrubs diversity. Forty plots were randomly placed in the entire area, representing all the vegetation type and localities. In each plot, trees and shrubs species were recorded and their height and diameter/collar diameter were measured for vegetational analysis frequency, density, abundance, and Importance Value Index (IVI) for tree and shrub species calculated by using the formula given by Curtis and Mc Intosh (1950).

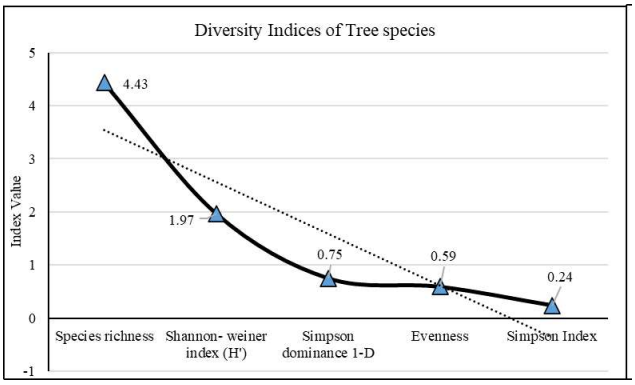
Diversity indices were also calculated by using the formula given by Shannon and Wiener (1963), Pielou (1969), Margalef (1957), Simpson (1949). Species diversity (H) was calculated using following formula as described by Shannon and Wiener (1963) and total basal cover as: (TBC) = Mean basal area of species × density of species. (Shah et al 2016).

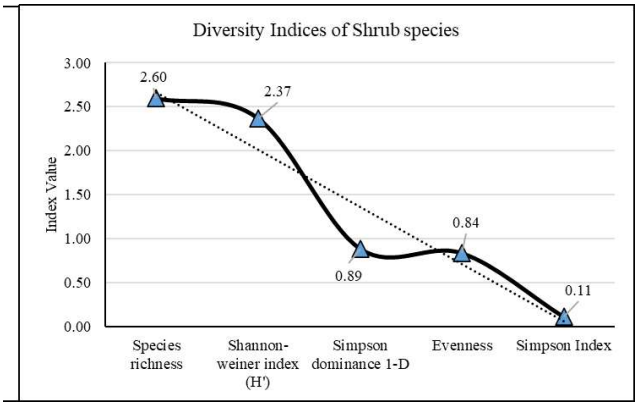
RESULTS AND DISCUSSION

In the present study, a total of 28 tree species and 17 shrub species were reported to assess the phytosociological status in Lansdowne Forest Division of Pauri Garhwal in Garhwal Himalaya. The maximum total basal cover was found for *Shorea robusta* (93082.04) and minimum was found in *Albizia lebbeck* (134.55) due to occurrence of species in few quadrates. The highest Frequency was for *Shorea robusta* (47.50%) followed by *Pinus roxburghii*, *Mallotus philippensis*, *Holoptelea integrifolia*. The maximum density was r for *Shorea robusta* (101.88) followed by *Pinus roxburghii* , *Acer oblongum* , *Holoptelea integrifolia* and *Mallotus philippensis.* The maximum importance value was for *Shorea robusta* (59.13) followed by *Pinus roxburghii*, *Adina cordifolia*, *Holoptelea integrifolia* (14.69), *Mallotus philippensis* (12.73), *Mitragyna parvifolia* (12.28), *Albizia procera* (10.93), *Bombax ceiba* (10.28) (Table 1).

The highest total basal cover was found in *Murraya koenigii* (4.71/25m^2) and the lowest total basal cover was found in *Woodfordia fruticosa* (0.07/25m^2). The highest frequency of shrub species was in *Lantana camara* (45%), *Murraya koenigii* (45%) followed by *Eupatorium adenophorum, Clerodendrum infortunatum* , *Rhus parviflora*. The highest density was found in *Eupatorium adenophorum* (2.00/25m^2) followed by *Rhus parviflora, Lantana camara*, *Murraya koenigii*, *Maesa motana*. However, the highest importance value was of *Lantana camara* (49.36) followed by *Murraya koenigii*, *Rhus parviflora*, *Eupatorium adenophorum* and *Maesa motana* (Table 2).

Diversity indices: In tree species, the trendline of various diversity indices shows the peak for species richness (4.43) and gradually decreases for Shannon-Wiener index (1.97), Simpson dominance (0.75), evenness (0.59) and Simpson index (0.24), respectively. Similarly, the trendline of diversity indices for shrub species indicate the species richness at its peak and gradually decreases for other indices, forward.





Ethnomedicinal uses of the tree and shrub species: In current study, a total of 45 plant species were identified during field observation in Lansdowne Forest Division, and

Table 1. Phytosociological status of tree species in Lansdowne Forest Division, Pauri Garhwal

Species	TBC/ha	Frequency	Density/ha	IVI
Acer oblongum	16499.27	5.00	11.25	10.04
Adina cordifolia	22686.61	12.50	7.50	15.88
Aegle marmelos	538.22	2.50	0.63	3.53
Albizia lebbeck	134.55	2.50	0.63	1.83
Albizia procera	3980.89	5.00	1.25	10.93
Anogeissus latifolia	4433.83	2.50	2.50	6.63
Bombax ceiba	2132.22	2.50	0.63	10.28
Cassia fistula	2534.11	12.50	5.63	8.40
Cassine glauca	1433.72	7.50	1.88	5.80
Diospiros montana	340.59	2.50	1.25	2.21
Erythrina suberosa	2911.74	7.50	4.38	6.45
Holoptelea integrifolia	14345.82	17.50	11.25	14.69
Lannea coromandelica	2105.89	10.00	3.13	7.04
Mallotus philippensis	3776.83	20.00	9.38	12.73
Mitragyna parvifolia	5105.72	2.50	1.25	12.28
Moringa oleifera	1305.93	2.50	0.63	6.78
Myrica esculenta	497.61	2.50	0.63	3.36
Pinus roxburghii	42889.37	32.50	88.13	46.81
Quercus leucotrichophora	3809.03	5.00	4.38	5.96
Rhododendron arboreum	1204.22	2.50	1.25	4.03
Sapium insigne	407.64	5.00	1.25	3.38
Schleichera oleosa	898.19	5.00	1.25	4.42
Semecarpus anacardium	3085.24	7.50	2.50	7.27
Shorea robusta	93082.04	47.50	101.88	59.13
Tectona grandis	3818.12	5.00	2.50	7.01
Terminalia tomentosa	5598.13	7.50	3.13	8.97
Toona ciliate	2070.86	2.50	0.63	10.02
Wrightia arborea	1039.31	5.00	3.75	4.16

Table 2. Phytosociological status of shrub species in Lansdowne Forest Division, Pauri Garhwal

Species	TBC/25m^2	Frequency	Density/25m^2	IVI
Berberis aristate	0.042	5.00	0.10	2.82
Carissa opaca	0.127	2.50	0.05	1.84
Cestrum aurantiacum	0.363	2.50	0.08	2.92
Clerodendrum infortunatum	1.85	30.00	1.00	26.76
Colebrookea oppositifolia	1.2	17.50	0.75	17.52
Eupatorium adenophorum	1.52	37.50	2.00	36.60
Glycosmis pentaphylla	0.025	2.50	0.05	1.43
Inula capa	0.173	7.50	0.28	5.71
Justicia adhatoda	0.726	12.50	0.30	9.99
Lantana camara	4.584	45.00	1.73	49.36
Maesa motana	3.83	20.00	1.10	32.12
Murraya koenigii	4.71	45.00	1.53	48.21
Pogostemon beghalensis	0.423	7.50	0.15	5.69
Rhus parviflora	3.465	25.00	1.75	37.91
Rubus ellipticus	1.267	10.00	0.65	14.26
Senna occidentalis	0.220	2.50	0.15	3.07
Woodfordia fruticose	0.07	5.00	0.20	3.77

their medicinal importance were documented from secondary sources. On the basis of secondary literature available on medicinal importance of these plant species, 24 species in curing skin disorders, 23 species in fever, 23 species in dysentery, 21 species in diarrhoea, 19 species in constipation, 18 species in headache, 17 species in pain killer, 15 species in ulcer, 13 species in muscle sprains, 13 species in cholera, 12 species in tumors, 12 species in cough, 12 species in leucorrhoea, and 11 species in toothache are widely used in various parts of the country (Fig. 1).

Among 45 species, the leaves of 24 species, bark of 17 species, root of 13 species, fruit of 12 species, seed of 10 species, flower of 7 species and gum of 5 species are extracted to utilize in treatment of various diseases (Fig. 2).

Phyto-sociological parameter such as basal area, frequency, density, importance value index and diversity indices play important role to identify the community structure and composition and its pattern in an ecosystem. The current study was conducted to find the variation in species diversity and composition of 28 trees and 17 shrubs species in Lansdowne Forest Division of Pauri in Garhwal Himalaya. The results obtained from present study are well aligned with the results reported earlier by many authors who worked in different parts of Himalayan region and country.

The total basal cover was recorded from range of 215.29 to 4984.57 for *Albizia lebbeck* and *Mitragyna parvifolia* which is similar to the basal cover reported by (Singh et al 1994) in Kumaun Himalaya. Moreover, the total basal cover for species was reported on the basis of their numbers present in all quadrate. However, the anthropogenic disturbance or maladaptation in some parts of Forest Division might be responsible for number of stems of the species. The density was reported between a range from 0.63 to 101.88 tree ha^{-1} present in study area which is similar to the value reported by Negi et al (2018) and Rawat et al. (2018) while working in mixed broadleaf forest of Garhwal Himalaya. However, the importance value index was found within the range from 59.13 to 1.83 in present study. Moreover, the IVI was used as a relative measure of the ecological perspectives and corresponded to resource apportionment within the plant community. Geometric

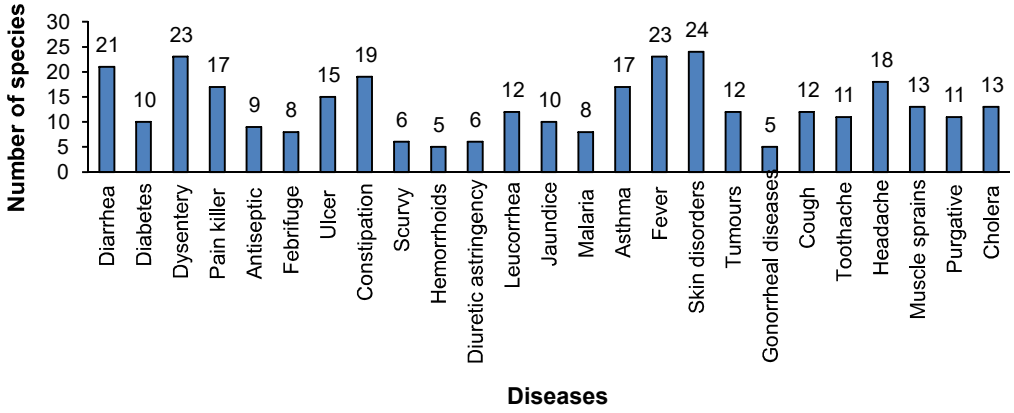


Fig. 1. Medicinal uses of species present in Lansdowne Forest Division

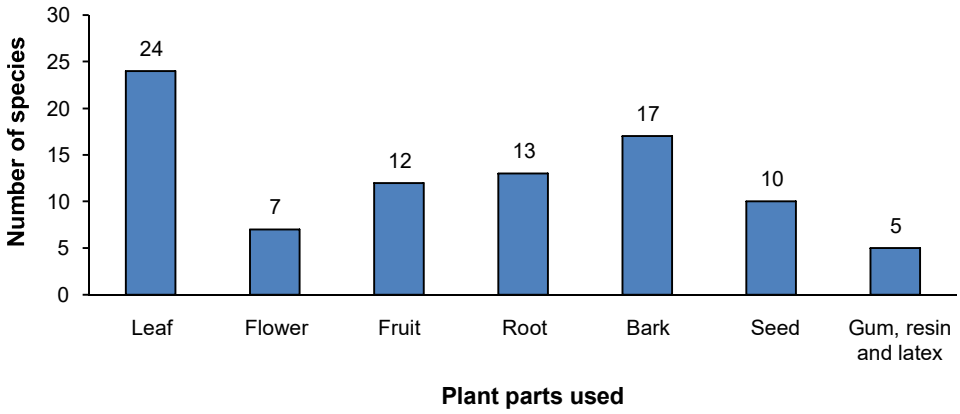


Fig. 2. Plant parts used in curing various diseases

distribution is usually exhibited by the ecological population which have low species community subject to low competition due to the proportion of utilization pattern of species IVI (Whittaker 1972).

The Shannon-Wiener index value of species were reported in the present study was similar to reported by Gairola et al (2011) while working in moist tropical montane valley of Garhwal Himalaya. The reason for variation in diversity in the study region may be due to the wide range of geographic factors such as altitude, aspect, temperature, rainfall and productive soil. Generally, the species diversity is directed by long term ecological process that influence the community stability and evolutionary time period (Verma et al 2004). However, the value of Simpson dominance (0.75) was close to the value reported by Rawat and Rawat (2010). The values of Simpson dominance depend on species richness and the lower values are associated with high species richness and *vice versa* (Malik 2014, Malik and Bhatt 2015). Though, evenness for species in present study was close to the study done by Gairola et al (2011). It has been always observed and confirmed the opposite relationship between Shannon-Wiener diversity and Simpson Index (Khumbongmayum et al 2005, Gairola et al 2011, Malik and Bhatt 2015).

AUTHORS CONTRIBUTION

The First author Shubham Chauhan (SC) and A. K. Negi (AKN) conceptualized the idea. SC performed the sampling and tabulation of the data. Dinesh Singh (DS) performed the analysis of data. SC and Dharmendra Shah (D) wrote the manuscript. DS and AKN reviewed and finalized the manuscript.

CONCLUSION

The conservation biodiversity is essential to understand the species distribution and factors governing the community structure and composition in western Himalaya. The present study reveals that how the variation in community structure plays vital role in conservation of biodiversity. The phytosociological status and diversity indices affect the plant communities (either tree or shrub) and give a better assessment about their distribution pattern. However, the conservation of biodiversity in the region is important to conserve the customary health care system, which is concentrated in the local community. The ethno-medicinal properties of these plant species are not sufficient to deal with sustaining the utilization as medicinal resources. Therefore, it is important to study and focus on these plant species in Himalayan region for sustaining the forest ecosystem in future perspectives.

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Genetic Variation in Wood Mechanical Properties Among *Eucalyptus* Clones

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Abstract**:** *Eucalyptus* spp. is considered as major commercial fast-growing pulp-wood species of Gujarat. Farmers of this region are keen interested in cultivation of this species. Therefore, study was carried out in the campus of Navsari Agricultural University, Navsari, Gujarat to evaluate eighteen different high yielding clones of *Eucalyptus* for its yield and strength properties. The trial was established in randomized block design with three replications and planted at 2 X 2m spacing. At the age of four years, trees were selected and harvested for recording wood mechanical properties such as compressive strength, tensile strength and static bending (MoE and MoR) to understand the suitability of wood for different end uses including pole. Result shows that the compressive strength, MoE and MoR varied significantly among 18 clones. Further, the basic density of wood had positive correlation with MoE (r=0.561) and MoR (r=0.571). Among 18 *Eucalyptus*clones, EC-12>EC-8>EC-4>EC-5>EC-11 performed superior in terms of mechanical strength, hence, these clones are suggested for pole to be utilized in various structural applications. Among 18 *Eucalyptus* clones, EC-12>EC-8>EC-4>EC-5>EC-11 performed superior in terms of mechanical strength, hence, these clones are suggested for pole to be utilized in various structural applications.

Keywords*:* Clonal variation, Compressive strength, *Eucalyptus* spp., Static bending, Tensile strength

Eucalyptus spp. is a major exotic tree species grown throughout the country for the production of pulp and paper as well as pole for construction (Luna et al 2009, Huse et al 2018). In Gujarat, forest department and paper & pulp industries are raising *Eucalyptus* plantation commercially across the state for pulp, plywood and as a pole for construction purpose. By looking into the economic benefit and early rotation, several farmers of Gujarat are growing *Eucalyptus* in their farmlands as block plantation and on the farm bunds also (Huse et al 2016). It is important to understand the genetic variation in mechanical properties as well as suitability of *Eucalyptus* clones in the south Gujarat condition so that suitable clones for large scale plantation in this agroclimatic situation can be selected in order to obtain higher productivity as well as profitability (Huse et al 2012). Mechanical properties of wood such as compressive strength parallel to grain, compressive strength perpendicular to grain, shear strength parallel to grain, static bending strength, impact bending strength, tensile strength perpendicular to grain and hardness are the most commonly measured strength parameters to test the suitability of timber for various end uses (Izekor et al 2010, Pima 2015, Saravanan et al 2014). Since *Eucalyptus* is highly used for pole purpose by the construction industries, especially in south Gujarat, so there is a great demand for good genotypes that provide good strength as pole. Hence, the present investigation was undertaken with an objective to identify the superior clones using 18 commercial *Eucalyptus* clones for short rotation forestry that suits for pole requirement by the construction industry well spread along the industrial corridor connecting Mumbai and Ahmadabad.

MATERIAL AND METHODS

Study area: The present investigation was carried out at Navsari Agricultural University, Navsari, Gujarat, India (20.95^0 N latitude, 75.90^0 E longitude and at 12 m MSL) during 2014-15 to 2016-2017. This region belongs to tropical climate characterized by fairly hot summer, moderately cold winter and more humid and warmer monsoon with average annual precipitation of 1355 mm.

Methodology: This paper covers the research findings of the clonal evaluation trial laid out with 18 commercial *Eucalyptus* clones including four from Institute of Forest Genetics and Tree Breeding, Coimbatore, Tamil Nadu. The trial was established for a period of four years following Randomized Block Design (RBD) at Navsari Agricultural University, Navsari. In the present study, total six ramets (trees) per clone were harvested at the age of four and used for assessment of wood mechanical property variation among 18 clones. Wooden samples were collected from all the harvested clones and the mechanical properties such as static bending, compressive strength parallel to grain and tensile strength parallel to grain were estimated following Rajput et al (1996) with Indian Standard Specification IS

1708 (Part 1-18):1986 (ISI 1986). These properties were tested by using Universal Testing Machine (UTM) of 50 kN capacity (Make: Shimadzu Analytical Private Limited).

For determination of compressive strength parallel to grain (MCS), the specimens were prepared as per IS: 1708 (Part 8)-1986. Specimens were having cross-sections 2 x 2 cm and 8 cm in length and the rate of loading was 0.6 mm min^{-1}. The compressive strength parallel to the grain (MCS in kg cm^{-2}) was calculated by the equation:

$$\text{Maximum crushing strength (MCS)} = \frac{Pmax}{A}$$

Where, Pmax = maximum crushing load at break point (Kg) and A = area of cross section of the specimen on which force was applied (cm^2).

Tensile strength: The test specimens for tensile strength were prepared are as per IS: 1708 (Part 12)-1986. Specimens used were dumbbell shaped and had cross section of 2 x 2 cm and length of 26.4 cm. The tensile strength parallel to grain (TS at ML in $kgcm^{-2}$) was calculated.

$$\text{Tensile stress at maximum load (TS at ML)} = \frac{Pmax}{A}$$

where, P max = maximum load required for failure perpendicular to grain (Kg) and A = area of the spe cimen on which force was applied (cm^2).

Static bending strength: For determination of static bending strength, the specimens were prepared as per IS: 1708 (Part 6)-1986. Specimens used were having a cross-section of 2 x 2 cm, length of 30 cm and with span length of 28 cm. The loading was applied at a constant rate of 1.0 mm/min on the tangential surface of the sample. Static bending strength parameters such as modulus of rupture (MoR in kg cm^{-2}) and modulus of elasticity (MoE in kg cm^{-2}), were worked out.

$$\text{Modulus of rupture (MoR)} = \frac{3 \times Pmax \times 1}{2 \times b \times h^2}$$

$$\text{Modulus of elasticity (MoE)} = \frac{P \times 1^3}{4 \times D \times b \times h^3}$$

Where, P = load at the limit of proportionality (kg); Pmax = maximum load (kg), l = span of the test specimen (cm), b = breadth of the test specimen (cm), h = depth of the test specimen (cm), D = deflection at the limit of proportionality (cm).

Statistical analysis: The experimental data were subjected to statistical analysis using statistical software (Sheoran et al 1998). Pearson's correlations analysis was performed to determine the relationship between wood density and the mechanical properties using the same software.

RESULTS AND DISCUSSION

Clonal variation for mechanical strength: The maximum crushing stress showed non-significant variation among 18 clones, however, the mean values varied from 445.60 to 592.77 kg cm^{-2}. Similar to tensile strength, clones EC-12, EC-10 and EC-11 also showed higher compressive strength than other clones. Similar range of variation for compressive strength was reported by Pima (2015) and ranged from 427.6 to 583.48 kg cm^{-2} among eucalypts clones (Table 1).

The tensile strength varied significantly from 751.46 (clone EC-6) to 1250.20 kg cm^{-2} (clone E-4) with overall mean 966.74 kg cm^{-2}. The clones such as EC-4, EC-12 and EC-11 recorded high tensile strength parallel to grain and may be good for roof trusses.

Static bending : The static bending strength varied significantly among 18 *Eucalyptus* clones. The modulus of elasticity (MoE) ranged from 667.08 $x10^2$ (clone EC- 18) to 1320.81 x 10^2 kg cm^{-2} (clone EC-12) among 18 clones with overall mean 950.25 x 10^2 kg cm^{-2}. Pima (2015) also reported similar observations where MoE estimated for various *Eucalyptus* clones ranged from $869x10^2$ to $1296x10^2$ kg cm^{-2}. This variation among clones is attributed by genetic characters. However, several wood anatomical properties may also affect the MoE of wood (Bhat and Priya 2004). For instance, thicker fiber wall and longer fiber length may affect the MoE (Pima 2015). Moreover, the sapwood and heartwood samples extracted from a same wood log may show variation in mechanical properties. Bal and Bektas (2013) studied the variation in mechanical properties of sapwood and heartwood of *E. grandis* and similar values of MoE reported to be 100.40 and $841.20x10^2$ kg cm^{-2} respectively in sapwood and heartwood for *E. grandis*.

The values of MoR ranged from 782.70 (clone EC-16) to 1527.32 kg cm^{-2} (EC-12) with overall mean 1004.98 kg cm^{-2}. Such observation was also recorded by several scientists in *Eucalyptus* spp. (Olufemi and Malami 2011; Bal and Bektas 2013, Pima 2015) and their range for MoR were in line with our result. Among 18 *Eucalyptus* clones, E-12, E-4 and E-8 clones showed higher MoR and MoE values in static bending.

Comparative profile of mechanical properties of seven *Eucalyptus* species and some other important timber yielding species is overviewed at Table 2. The findings of this experiments on various mechanical properties studied in *Eucalyptus* clones are comparable not only with the standard timber Teak (Shukla et al 2007) but also with *Melia dubia* (Saravanan et al 2014), *Casuarina* spp. (Patel 2023) and with some other lesser-known trees of Mizoram (Hegde 2019) too. This shows the suitability of some superior tested clones of *Eucalyptus* for its use as poles and for other structural applications.

Correlation between mechanical properties with wood density: The relationship between wood mechanical

Table 1. Clonal variation for wood mechanical properties among 18 *Eucalypts* clones at 4 years age

Clone	Compressive strength parallel to grain [MCS (kg cm^{-2})]	Tensile strength parallel to grain [TS at ML (kg cm^{-2})]	Static bending	
			MOE (10^2 kg cm^{-2})	MOR (kg cm^{-2})
EC-1	445.60	960.36	1023.30	857.73
EC-2	546.05	869.38	1086.45	1046.28
EC-3	539.53	871.00	991.51	900.87
EC-4	529.14	1250.20	1025.25	962.51
EC-5	535.81	1001.46	976.95	1107.61
EC-6	546.21	751.46	1135.79	1106.49
EC-7	509.72	1024.08	905.25	963.35
EC-8	582.68	985.83	972.06	1039.92
EC-9	529.01	967.95	935.62	1178.06
EC-10	581.92	1004.46	915.56	951.59
EC-11	549.01	1149.51	911.12	965.24
EC-12	592.77	1184.8	1320.81	1527.32
EC-13	454.56	940.49	908.95	874.88
EC-14	461.66	775.34	786.41	1020.03
EC-15	473.82	911.57	851.52	1016.77
EC-16	495.37	999.47	848.90	782.70
EC-17	532.59	849.57	841.92	973.59
EC-18	472.58	904.33	667.08	814.69
Mean	521.00	966.74	950.25	1004.98
CD (p=0.05)	NS	176.84	136.39	144.23

Table 2. Comparative profile of mechanical properties of *Eucalyptus* spp. and other timber species

Species/ Mechanical properties	Compressive strength parallel to grain [MCS (kg cm^{-2})]	Bending strength [TS at ML (kg cm^{-2})]	MoE (x10^2 kg cm^{-2})	MoR (kg cm^{-2})	References
Eucalyptus clones	490 to 650	-	-	-	Pima et al. (2000)
E. urophylla x E. grandis	742	1410	1734	-	Anon. (2006)
E. grandis	570	1230	1268	-	Anon. (2006)
E. urophylla	620	1730	2547	-	Anon. (2006)
E. tereticornis	770	1460	1739	-	Anon. (2006)
E. camaldulensis	619	-	1532	1333	Olufemi and Malami (2011)
E. saligna	394	-	-	-	Olufemi and Malami (2011)
E. robusta	286	-	-	-	Olufemi and Malami (2011)
E. grandis	458	-	-	-	Olufemi and Malami (2011)
E. butryoides	553	-	-	-	Olufemi and Malami (2011)
E. grandis sapwood	600	-	1007	1000	Bal and Bektas (2013)
E. grandis heartwood	520	-	841	840	Bal and Bektas (2013)
Eucalyptus clones	419 to 572	-	853 to 1271	725 to 1085	Pima (2015)
Casuarina hybrids	364	553	737	800	Patel (2023)
Thespesia populnea	358	-	726	787	Kantariya and Sinha (2023)
Tectona grandis	520	-	1170	941	Shukla et al. (2007)
Melia dubia	-	-	684	852	Saravanan et al. (2014)
Anogeissus acuminata	728	-	806	970	Hegde (2019)
Castanopsis tribuloides	592	-	865	777	Hegde (2019)
Duabanga grandiflora	408	-	751	719	Hegde (2019)
Schima wallichii	618		882	1021	Hegde (2019)

Units for mechanical properties are brought under common unit.

Table 3. Correlation between basic density and mechanical properties in *Eucalyptus* clones using Pearson's Correlation analysis

Physical & mechanical properties	CS	TS	MoE	MoR	BS
1. CS (Compressive strength parallel to grain)	1.000				
2. TS (Bending strength)	0.337^{NS}	1.000			
3. Modulus of Elasticity (MoE)	0.561*	0.312^{NS}	1.000		
4. Modulus of Rupture (MoR)	0.571*	0.237^{NS}	0.709**	1.000	
5. Basic density (BS)	0.363^{NS}	0.247^{NS}	0.650**	0.867**	1.000

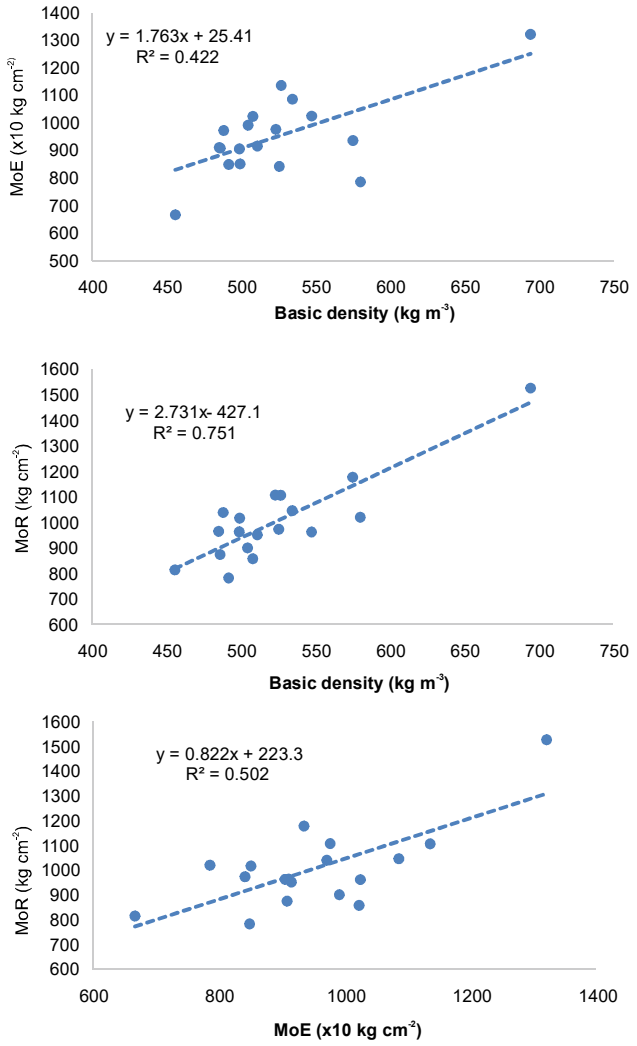

Fig. 1. Association between basic density of wood with MoE and MoR among 18 *Eucalyptus* clones

properties with basic density among 18 *Eucalyptus* clones was assessed. There was a significant correlation between compressive strength (parallel to grain) with MoE (r=0.561) and MoR (r=0.571); however, it was non-significant between compressive strength (parallel to grain) and tensile strength (parallel to grain). Furthermore, MoE was also positively correlated with MoR (Table 3). Basic density is one of the important physical parameters used in the assessment of wood quality, hence, basic density of wood was correlated with all the four wood mechanical properties. The basic density of wood showed positive correlation with MoE and MoR. Figure 1 shows the influence of basic density of wood on MoE and MoR and between MoE and MoR. Similarly, Edward and Matsumura (2016) also found a strong positive significant linear relationship between MoE and MoR in *Pinus kesiya.* Sharma et al (2005) also worked out correlation between wood density with mechanical properties and observed positive relationship in *Eucalyptus tereticornis*. This indicated that wood density can potentially be used as an indicative trait for predicting mechanical properties of wood in *Eucalyptus* spp.

CONCLUSION

Among 18 *Eucalyptus* clones studied for variation in wood mechanical properties, EC-12>EC-8>EC-4>EC-5>EC-11 clones showed superior wood quality in terms of mechanical properties. Therefore, these clones can be used as pole for various structural applications. Moreover, these selected clones may be used for commercial plantations and also for further breeding programme to obtain higher productive potential.

AUTHORS CONTRIBUTION

Dr. R. P. Gunaga helped in technical aspects, Dr. S.K. Sinha helped in wood analysis and Dr. L.K. Behera helped in field data collection.

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Studies on Effect of Pre-Sowing Seed Treatments on Seed Germination and Seedlings Vigour of *Buchanania lanzana* Spreng

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Abstract: *Buchanania lanzana (Chironji)* has high socioeconomic value providing livelihood to tribal population of the area and has high potential as commercial agroforestry species. At present, the plant is grouped as an underexploited and non-nationalized minor forest produce. It is free for collection, because of which the local inhabitants, traders, and merchants destroy the branches/whole trees during the collection of its fruits without bothering about its regeneration. This has led to the destruction of chironji plants in the forests. Hence, there is an urgent need to develop a technology for easy multiplication and regeneration of chironji, and to popularize its importance among local inhabitants/tribals. Germination is one of the main problems in plant propagation by seed. The very hard seed coat of chironji makes it impermeable to imbibition and gas exchange resulting in low germination and vigor. The present study was carried out to assess the possibility to get the maximum percent of germination in *Buchanania lanzan* seeds which were treated with different pre-sowing treatments. Among the different pre-sowing treatments cow dung slurry for 48 hours showed the highest germination percentage (84.5%), peak germination value (3.97), mean daily germination (3.01), speed of germination (11.9) and total seedling height (17.65 cm).

Keywords: Chironji, Socioeconomic, Destruction, Regeneration, Pre-sowing, Germination percentage

Chironji (*Buchanania lanzan* Spreng.), often called charonji, is a member of the Anacardiaceae family, originated in the Indian sub-continent, and is an excellent tree for agroforestry. It assumes great significance due to its multifarious uses and capacity to withstand adverse climatic conditions. The tree grows naturally in India's tropical deciduous woods, primarily in the states of Madhya Pradesh, Bihar, Orissa, Andhra Pradesh, Chhattisgarh, Jharkhand, Gujarat, Rajasthan, and Maharashtra (Kumar et al 2012, Avani 2015). It is an Indian Western Ghats medicinal tree that is on the verge of extinction due to habitat loss, prolonged dormancy and tree uprooting for its medicinal value (Ajith et al 2018). In accordance with the country's many agro-climatic zones, Chironji plants blossom from January to March. Fruits ripen from April to June, and the bulk of seed collection occurs during this period (April). Early harvesting has a detrimental effect on the germination and quality of their seeds. Both seeds and vegetative methods (softwood grafting, chip budding, and root cutting) are used to grow chironji (Thounaojam et al 2020). Currently, it is growing under forest conditions as an underexploited and non-nationalized minor forest produce and gives monetary benefit to tribal communities in Chattisgarh (Rajput et al 2018). The kernel is highly nutritious and rich in protein (25-30%) and yields sweet oil, which can be used to substitute olive and almond oil (Avani et al 2015). Trees have an alternate bearing nature as present in the mango (Rajput et al 2018). Kernels are of very high value and fetch Rs. 800-1000 per kg in the market (Gohil et al 2016). This versatile tree serves the community's needs for food, fire, fodder, timber, and medicine (Dwivedi et al 2012). It is a common and delectable nut fruit that can be consumed either raw or roasted and is also used to make desserts (Avani et al 2015). Locals use its leaf as green fodder for their animals, particularly buffalo, goats, and sheep, during the summer when green fodder is scarce. Wood is dried and used as fuelwood. Because it is free to collect, locals, traders, and merchants cut down whole branches and trees to get the fruit, disregarding the need for fresh plants. As a result, Chironji plants in the woodlands have been decimated (Dwivedi et al 2012). As the species is used in commercial horticulture, this species has significant socioeconomic importance. Unfortunately, over exploitation and careless harvesting (lopping and chopping) pose a serious threat to it, necessitating urgent conservation measures at all levels. More land being covered by new plantations is the strategy to increase and preserve the Chironji plantation. Keeping in mind these facts and to satisfy the local need for chironji planting material of high grade is required (Rajput et al 2018). The main issue with the seed is the hard seed coat, which results in low germination and the availability of seeds only for a short time (April). There is also a problem with

germination because the seeds are more susceptible to fungal and microbial invasion (Usha 1996). Given the significance of *Buchanania lanzan* and the difficulties associated with seed propagation, understanding the elements that contribute to poor germination in seeds as well as how to overcome these obstacles would be helpful for large-scale multiplication. In light of this context, the study was initiated with the following goals: to examine pre-sowing seed treatment for improving germination, and determine the optimal treatment for producing high-quality seedlings.

MATERIAL AND METHODS

The present study was carried out at College of Forestry, Ponnampet, Karnataka, India, located in the central part of Western Ghats. *Buchanania lanzan* fruits were collected from middle aged trees and seeds were de-pulped by soaking in normal water. Collected seeds were thoroughly hand mixed to ensure the homogeneity of each lot before grading. *Buchania lanzan* seed germination experiments were conducted in a Completely Randomized Design with different treatments namely T1-Water soaking for 72 hours; T2- Alternate wetting (12 h) and drying (12 h) two cycle for 48 h; T3- Alternate wetting (12 h) and drying (12 h) three cycle for 72 h; T4- AWD 48 hours + $GA_3$500 ppm for 12 h; T5- Soaking seeds in lime solution for 24 h; T6-Lime+jagger solution for 24 hours; T7- Cowdung slurry for 48 hours; T8- Soaking in cow urine for 48 hours; T9-Control.

In each treatment, four replications with 400 seeds were used per replication and total 3600 seeds were sown in different root trainers having potting mixture prepared by adding Soil: Sand: Vermicompost in 2:1:1 ratio. Filled root trainers were placed in a nursery bed. The root trainers were watered regularly on daily basis. Following observations were recorded. The nursery bed was observed daily, for seedling emergence. The day on which the first seedling emerged was expressed as days to initial germination. The number of days on which the last seedling emerged was recorded and expressed as days to final germination. Speed of germination was calculated by the following formula- Speed of germination= n1/d1+n2/d2+n3/d3+----------, Where, n = number of germinated seeds; d= number of days. Germination per cent was calculated as number of normal seedlings/total number of seed sown x 100. Peak value of germination (PV), which denotes the speed of germination, which is the maximum mean daily germination, recorded at any time during the period of test. Germination value (GV) was calculated using the following formula GV = MDG x PV (Czabator1962). Seedling growth parameters like collar diameter, shoot length, root length, and total seedling length were measured as per standard procedures. To record seedling dry weight all normal seedlings were dried under shade for 24 hours and then dried in hot air oven maintained at 70± 1°C for 72 hours. It was cooled in a desiccator for 30 minutes and weighed in grams. Dry weight of individual seedlings was computed and expressed as g per seedling. Seedlimg index was calculated using formula- Vigour index = Germination percentage x Total dry weight (Abdul-Baki and Anderson, 1973). Similarly, quality of produced seedling was determined by using Seedling Quality Index

$$\text{Quality index} = \frac{\text{Total dry weight of seedlings (g)}}{\frac{\text{Height of seedling (cm)}}{\text{Diameter of seedlings (mm)}} + \frac{\text{Shoot dry weight (g)}}{\text{Root dry weight (g)}}}$$

RESULTS AND DISCUSSION

The initial germination ranged from 9 (T1 and T7) - 13 days (T9) and days taken to final germination ranged between 27-28 days in all the treatments except T5 (Table 1). Peak value of seed germination varied from 1.14 (T9) to 3.95 (T7). Values of seed germination varied from 26.50 % (T9) to 84.50 % (T7). Values of speed of germination varied from 3.21 (T9) to 10.16 (T1).

Thus, seed germination and different associated parameters varied for different pre-sowing treatments. Among the different pre-sowing seed treatments, treating seeds with cow dung slurry for 48 hours was found to be better. The similar trend was observed in *Melia dubia* and sandalwood seeds soaked in cowdung slurry for seven days showed increased germination speed, germination percentage, seedling growth and biomass production compared to the control treatments (Anand et al 2012, Sutheesh et al 2016).

The highest germination percentage among the treatments is observed in treatment T7 *i.e.* seeds treated with cowdung slurry for 48 hours (84.5%), followed by treatment T1 i.e. seeds soaked in water for 72 hours (78.5%) and least was observed in T9 (26.5%). Similar trend of maximum germination (66.11%) of *Manilkara hexandra L.* were recorded in treatment, 12 hrs soaking in cattle urine+ 12 hrs keeping in cow dung slurry followed by 24 hrs soaking in cattle urine (20%). The higher germination percentage in cattle urine and cowdung slurry treatment may be attributed to the presence of growth promoting substances (auxins) in cattle cowdung (Shinde et al 2015). Collar diameter recorded significant difference between the treatments. Seeds treated with lime solution for 24 hours showed highest value of collar diameter of 2.16 mm, followed by seeds treated with AWD (Alternative Wetting and Drying) for 72 hours (2.11 mm) and least value (1.65 mm) of collar diameter was observed in seeds treated with lime + jaggery solution for 24 hours. Shoot length showed significant differences between the treatments (Table 2). Seeds treated with AWD for 48 hours +

Table 1. Effect of different pre-sowing seed treatment on seed germination characteristics of *B. lanzan*

Treatment	Days to initiate germination	Days to final germination	Peak value of germination	Mean daily germination	Speed of germination	Germination (%)
T1	9	28	3.43	2.80	10.16	78.50
T2	11	28	2.72	2.39	8.51	67.00
T3	10	28	2.48	2.01	7.28	65.00
T4	10	28	2.24	1.91	7.12	53.50
T5	12	27	2.07	1.85	6.03	52.00
T6	12	28	1.39	1.28	4.18	36.00
T7	9	28	3.95	3.01	11.9	84.50
T8	-	-	-	-	-	-
T9	13	28	1.14	0.94	3.21	26.50
CD (p=0.05)	NS	NS	1.40	1.16	4.24	12.98
CV	31.48	31.22	32.47	33.24	32.84	15.27

T1-Water soaking for 72 hours; T2- Alternate wetting (12 h) and drying (12 h) two cycle for 48 h ; T3- Alternate wetting (12 h) and drying (12 h) three cycle for 72 h; T4- AWD 48 hours + $GA_3$500 ppm for 12 h; T5- Soaking seeds in lime solution for 24 h; T6-Lime+jagger solution for 24 hours; T7- Cowdung slurry for 48 hours; T8-Soaking in cow urine for 48 hours; T9-Control

Table 2. Effect of different pre-sowing seed treatment on seedling characteristics of *B. lanzan*

Treatment	Collar diameter (mm)	Root length (cm)	Shoot length (cm)	Root-Shoot ratio	Total seedling height (cm)
T1	2.08	8.98	6.94	1.29	15.91
T2	2.09	9.98	6.88	1.45	16.85
T3	2.11	9.01	6.89	1.30	15.90
T4	1.80	8.45	9.36	0.90	17.81
T5	2.16	8.18	6.36	1.28	14.54
T6	1.65	10.35	6.69	1.54	17.04
T7	1.78	10.31	7.34	1.40	17.65
T8	-	-	-	-	-
T9	1.81	8.09	6.98	1.15	15.06
CD (p=0.05)	0.27	NS	0.97	NS	NS
C.V.	9.70	23.62	9.22	-	14.32

See Table 1 for details

GA_3 500 ppm shows highest value of shoot length of 9.36 cm, followed by seeds treated with cowdung slurry for 48 hours (7.34cm) and least value (6.36 cm) of shoot length was observed in seeds treated with lime + jaggery solution. Root length, total seedling height and Quality index did not show any significance between the treatments.

AUTHORS CONTRIBUTION

Dr. Vijayalakkshmi K.P- Prepared the manuscript as well as methodology, Dr. Ramakrishna Hegde - Helped in the statistical analysis of the data and corrected the manuscript, Shashank and Sudheesh - Collected seeds and conducted the experiment

CONCLUSION

The present study revealed that the treatment of cow dung slurry for 48 hours showed the highest germination percentage (84.5%) and best pre-treatment for quality seedling production of *Buchanania lanzan.*

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Potential and Performance of Poplars under Short Rotation Agroforestry Models: A Case Study of Yamunanagar District of Haryana

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Abstract: The biomass assessment of poplar (*Populus deltoides*) was done in Yamunanagar district based on different girth classes. The sample plots, each having a size of 0.1 ha were laid within each stratum for collecting the field data. The average biomass for 2.5 years old (30 to 59 cm girth class) and 3.5 years old (60 to 89 cm girth class) plantations was assessed (33.73 tha^{-1} and 49.16 tha^{-1}, respectively). This study concludes that agroforestry in the study area is passing through a transition phase and it is evolving to short rotation agroforestry models. Adapting to market dynamics, farmers prefer short rotation of less than 4 years over long rotation of 6 to 8 years. This study also gives useful information for planning various climate mitigation strategies as well as carbon sequestration projects through agroforestry which are directly dependent on biomass production besides giving a pathway for economy-driven planning and extension of agroforestry as well as wood based industries.

Keywords: Agroforestry models wood based industry, Biomass, Carbon sequestration, Mitigation

Successive reports of UNFCCC have been highlighting the importance and necessity of agriculture, forestry and other land use i.e., AFOLU sector as a mitigation tool to combat climate change. Forests, the reservoirs of carbon, which is proportionate to biomass production, are under various pressures due to ever-increasing demand for timber, fuelwood and various other products. The dependence on forests needs to be diverted to agricultural lands and to make agricultural lands also "productive and sustainable".

Rizvi et al (2022) reported an area of 28.4 MHA under agroforestry in India. The Forest Survey of India has estimated area under trees outside forests (TOF) as 29.3 MHA (ISFR 2021). The extent of area under agriculture in India is 141 MHA, out of which 78 MHA is irrigated, which is the potential area for extension of agroforestry. International Panel on Climate Change in 2023 summary for policy makers para A-3.2 and C-3.5 documents the potential adaptation options for forestry and agriculture sectors and identifies agroforestry under AFOLU sector as the ideal mitigation-adaptation mechanism. Poplar, a fast-growing agroforestry species, has an extent of 2,70,000 hectares in India (Chavan et al 2023), whereas in Yamunanagar district, it occupies an area of 12169.6 hectares i.e., 6.93% of geographical area (Rizvi et al 2020). The Indo-Gangetic plain is conducive for poplar cultivation, having 12,540 sq km (1.79%) currently under agroforestry, holds significant potential for expansion of agroforestry. The high productivity potential, availability of area under suitable agroclimatic zones i.e., Indo Gangetic Plain and plywood-friendly properties of poplars make it a preferred species for agroforestry. The objective of this study has been to assess the performance of poplar by recording their biomass productivity under short rotation agroforestry models in Yamunanagar district.

MATERIAL AND METHODS

Poplars occupy 6.93% of the geographical area in Yamunanagar district. The Haryana tree census 2023 conducted by the Haryana Forest Department, records Yamunanagar as a district having maximum area under agroforestry with 4.01 million poplar trees. The trees having a girth of 30 cm and above were measured and recorded under this study (GBH i.e., 1.37 m), which covered an area of 8126 hectares.

Yamunanagar district has Sandy-loam to loamy-sand soils (Agriculture Department, Haryana) with tubewell-based assured irrigation spread over 97% of its geographical area, suitable for poplar-based agroforestry. It is recognized as a focal point for wood-based industries (WBIs), housing a total of 1589 wood-based industries comprising 468 "Plywood and veneer units", 424 sawmills and 236 stand-alone presses, producing 50% of country's plywood. The prevalence of agroforestry in Yamunanagar district and its significance as a plywood industry hub of India formed the basis for selecting this district as area of study.

The prevalence of poplar within different administrative units of Forest Department i.e., Forest Ranges, were taken into consideration for the purpose of sampling included discussions with farmers as well as industrialists. Jagadhari Forest Range has 45% of the total poplar trees, hence the range was selected as study area (Fig. 1). Villages having more than 5000 poplar trees under agroforestry plantations were taken for sampling points. It was followed by selection of a suitable sampling plan, calculation of standard deviation, field measurements and finally the data analysis.

Selection of strata, sampling plan and data collection: Stratified Random Sampling strategy was used for the study. After conducting the field visits, the entire population in the study area was divided into two homogeneous strata based on girth classes i.e., 30-59 cm and 60-89 cm. This categorization was determined by the presence of plantations only within these specific girth classes in the field.

The variance of biomass within each stratum was calculated and a basis for determining the number of permanent sample plots was established using the standard statistical tool presented by Pearson et al (2007). To estimate the standard deviation in each stratum i.e., 30-59 cm and 60-89 cm girth classes, five sample plots each having a size of 0.1 ha (31.62 m x 31.62 m) were laid randomly in both the strata. Standard Deviation for both the strata having girth classes of 30-59 cm and 60-89 cm was calculated as 0.25 and 0.51, respectively based on which the number of sample plots calculated for these girth classes were 16 and 8, respectively.

Nested Square sample plots each having a size of 0.1 ha (31.62 m x 31.62 m), were laid for undertaking fieldwork. Stratified Random Sampling strategy using the rice grain method was used to identify the location of sample plots within each stratum separately. The rice grains were scattered on the map/toposheet of the selected area and the points where grains fell on the sheet were selected as the centre of sample plots. Measurement of the girth at breast height i.e. GBH (at 1.37m) of individual trees having girths greater than or equal to 30 cm was done using linear tape. GPS coordinates of all four corners as well as the central points of the sample plots were also taken using Google Maps. All measurements taken in field were recorded in standard proformas. Calculation of biomass was done using tools given in Table 1.

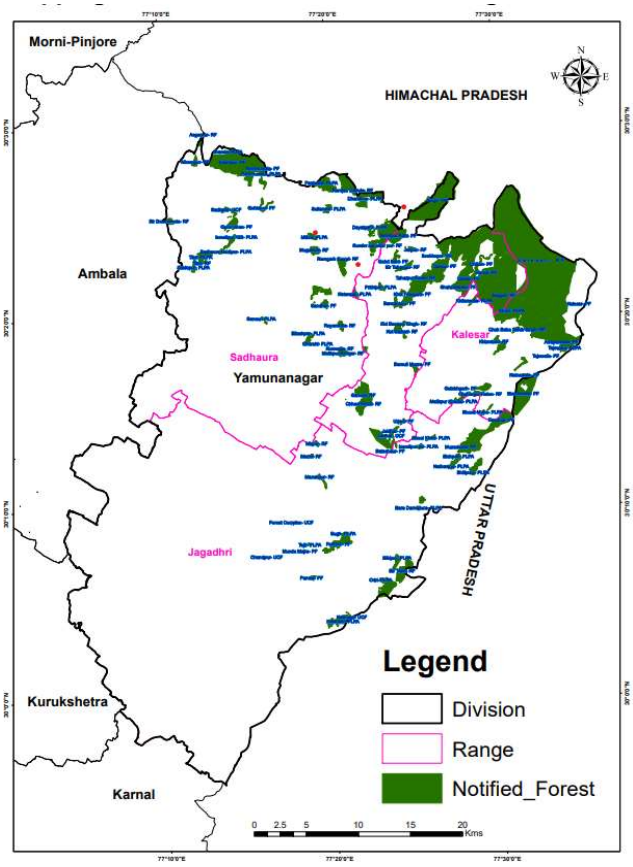

Fig. 1. Map of study area

RESULTS AND DISCUSSION

The assessment of biomass under the present study has been done for 2.5 years and 3.5 years old plantations having girth classes of 30-59 cm and 60-89 cm, respectively. Average tree density varied from 500 to 700 trees per hectare. The above ground biomass and below ground biomass i.e. AGB and BGB, respectively were calculated using standard values of wood density, biomass expansion factor and equations for volume as given in Table 2. AGB and BGB were then added to calculate the total biomass of each sample plot, which was further extrapolated to estimate the biomass per hectare.

The biomass was calculated for all sample plots under both strata. Sample plot wise calculation of biomass under the two selected strata has been given in Table 2 and 3. Using the year of plantation as base year, biomass production per ha per year was assessed as 16.8 $tha^{-1}yr^{-1}$ and 16.4 $tha^{-1}yr^{-1}$ under the girth classes of 30-59 cm and 60-89 cm, respectively. The assessed biomass productivity, rotation cycle and average tree density per hectare has been given below in Table 4.

It was confirmed during field visits that only two girth classes of poplar i.e., 30-59 cm and 60-89cm were available under agroforestry and further 75% of this crop was available in lower girth class only. The present study reports the biomass productivity of poplars under these girth classes having a reduced harvesting rotation cycle of less than four

Table 1. Dtandard values used for biomass calculation

Parameter	Description	Unit	Source	Value
GBH	Girth at breast heigh	m	Field work	Measurement from field in cms is divided by 100 to convert in mts
D	Diameter at breast height	m	Field work	GBH/3.14
V	Volume	m3	Volume equations FSI	V = 0.81467-1.063661D+6.452918D2 for Poplar, FSI Technical Information Series Volume 2 No. 1 2020, TOF
WD	Wood density	gm/cm3 or t/m3	FAO, ICRAF	0.37 (Poplar)- ICRAF Data base 0.57 for both species – by FAO
BEF	Biomass expansion factor	Constant	IPCC, GPG Table 3 A.1.10	1.3 - 3.4
AGB	Above ground biomass	Tonnes	Calculated from field work	AGB=V * WD * BEF
BGB	Below ground biomass	Tonnes	Calculated from AGB	BGB= AGB * 0.27 (IPCC default value)

Table 2. Biomass calculation for all samples of 30-59 cm girth-class

Name of Site	Spacing (ft)	Year of plantation	Volume (cum)	AGB (tons)	BGB (tons)	Total biomass of each sample plot (tons)	Biomass for each sample plot (t ha^{-1})
Kazibans (P-I)	13' × 13'	January-21	4.25	2.04	0.55	2.6	25.97
Ismailpur (P-I)	12' × 13'	January-21	4.4	2.12	0.57	2.69	26.87
Nandgarh (P-I)	13' × 13'	January-21	4.42	2.12	0.57	2.7	26.97
Parwalo (P-I)	13' × 13'	January-21	4.63	2.23	0.6	2.83	28.27
Bhilpura (P-I)	14' × 14'	January-21	4.92	2.36	0.64	3	30.03
Nandgarh (P-I)	13' × 13'	January-21	5.25	2.53	0.68	3.21	32.09
Ismailpur (P-I)*	12' × 13'	January-21	5.42	2.6	0.7	3.31	33.08
Lkr M. Partappur (P-I)*	14' × 14'	January-21	5.53	2.66	0.72	3.38	33.81
Amadalpur (P-I)*	13' × 13'	January-21	5.61	2.7	0.73	3.43	34.27
Mukarampur (P-I)	12' × 12'	January-21	5.88	2.83	0.76	3.59	35.9
Hangoli (P-I)	13' × 13'	January-21	5.92	2.85	0.77	3.62	36.15
Sugh (P-I)	10' × 16'	January-21	6.07	2.92	0.79	3.7	37.05
Sugh (P-I)*	10' × 16'	January-21	6.29	3.02	0.82	3.84	38.4
Nathanpur (P-I)	14' × 14'	February-21	6.41	3.08	0.83	3.92	39.16
Amadalpur (P-I)*	8' × 16'	January-21	6.42	3.09	0.83	3.92	39.19
Mukarampur (P-I)	12' × 12'	January-21	6.96	3.35	0.9	4.25	42.54
Average volume & Biomass, t ha^{-1}			5.52	2.66	0.72	3.37	33.73

*Plots randomly sampled for estimating standard deviation

Table 3. Biomass calculation for all samples, 60-89 cm girth-class

Name of site	Spacing (ft)	Year of plantation	Volume (cum)	AGB (tons)	BGB (tons)	Total biomass of each sample plot (tons)	Biomass for each sample plot (t ha^{-1})
Bakarpur (P-II)*	10' × 18'	January-20	6.6	3.18	0.86	4.03	40.33
Nandgarh (P-II)	13' × 13'	January-20	7.47	3.59	0.97	4.56	45.63
Khadri (P-II)	14' × 14'	February-20	7.76	3.73	1.01	4.74	47.43
Parwalo (P-II)*	13' × 13'	January-20	7.79	3.75	1.01	4.76	47.61
Nathanpur (P-II)*	14' × 14'	January-20	8.41	4.05	1.09	5.14	51.39
Sugh (P-II)*	10' × 16'	January-20	8.54	4.11	1.11	5.21	52.14
Kazibans (P-II)	13' × 14'	January-19	8.73	4.2	1.13	5.33	53.33
Hangoli (P-II)*	16' × 16'	January-20	9.07	4.36	1.18	5.54	55.43
Average volume & biomass, t ha^{-1}			8.05	3.87	1.05	4.92	49.16

*Plots randomly sampled for estimating standard deviation

Table 4. Biomass productivity in study area

Girth class/ stratacm	Rotation cycle/age (Year)	Average tree density per hectare (Number)	Biomass production		
			Productivity range (t ha^{-1})	Average productivity (t ha^{-1})	Average annual productivity (t ha^{-1})
30-59	2.5 yr	500-700	25.9-42.5	33.73	16.8
60-89	3.5 yr	500-700	40.3-55.4	49.16	16.4

Table 5. Comparative chart of average annual productivity of poplar under different studies

Rotation cycle (yr)	Average annual productivity ($tha^{-1}yr^{-1}$)	Assessment done by	Area of study
6	9	Handa et al (2020)	Haryana
7	4.5-11.5	Rizvi et al (2010)	Haryana & UP
6	30	Haque et al (2014)	Punjab
7	16.2	Rizvi et al (2019)	Haryana
6-8	21.9	Chavan et al (2023)	Indo Gangetic plain
2.5	16.4	Results of present study, 2023	Haryana
3.5	16.8	Results of present study, 2023	Haryana

years. With the introduction of spindle-less peeling machines and other technological advancements, the requirement of round timber in the plywood industry has reduced to a smaller diameter of 30-35cm, which previously required a diameter of 60cm. The harvesting rotation of poplars, as a result, which earlier used to be 6 to 8 years has come down to less than four years.

The comparison of productivity range of poplar under different studies with long rotation and the present study with short rotation has been given in Table 5. It shows that productivity under short rotation cycles is comparable with long rotations and there is no loss of biomass for the commercial use in the immediate scenario or in future.

Further, with the adoption of shorter rotations, farmers are also reducing the spacing from the current average of 13 ft x13 ft to 14 ft x 10 ft or 13 ft x 10ft. The number of plants to be planted per ha, consequentially, has also started increasing from 500-700 plants ha^{-1} under existing models to 850-900 plants ha^{-1} under new models. It will further result in increased biomass production per ha in the coming years as shorter rotations with increased density will be preferred. Short rotations with increased tree density will yield enhancement in biomass production though the outcome shall be ascertained in the coming years.

CONCLUSION

Keeping pace with the requirements of industry, farmers have switched over to plantation models with short rotation cycles of less than 4 years. The average annual productivity assessed under the present study for short rotations was found comparable with earlier assessments with long rotations. The findings of this paper auger well for the future of agroforestry as short harvesting rotations will support more plants per hectare and hence biomass production per unit area will also increase substantially.

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Urban Greenery: Assessing the Diversity and Ecological Role of Wall-Adherent Flora in Aligarh, (Uttar Pradesh) India

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Abstract: This study assesses the diversity and ecological importance of vascular and non-vascular wall-adherent flora in Aligarh, Uttar Pradesh. Through a comprehensive survey, we identified and documented the plant species growing on walls across different locations within the district. A total of 116 vascular plant species were documented, among which 92 were dicotyledonous, 21 were monocotyledons, and 3 were pteridophytes. Only two plant species of non-vascular flora (bryophytes) were observed. Members of the Poaceae, Asteraceae, and Amaranthaceae families were in the highest number compared to others. The Aligarh district's most widespread wall flora among perennial woody trees belongs to the species *Ficus*. The study emphasises the value of vascular wall-adherent flora as a crucial component of Aligarh's urban vegetation. The presence of a wide range of plant species, particularly woody perennials, atop Aligarh's city walls demonstrates the city's age and low level of urbanisation.

Keywords: Wall flora, Urban ecosystems, Urban vegetation, Biodiversity, Urbanisation, Vascular plant

Walls are man-made ecosystems that are regionally and globally dispersed. The best way to describe a wall ecosystems through their environmental and physical qualities, which also influence habitats and support life forms. In ecosystems, many biotic and abiotic variables are interconnected, but nutrients, physical substrate, microclimate, and moisture are the four essential ecosystem elements that are particularly important for walls. The fact that walls can be found in both rural and urban areas means that the pressure exerted by the nearby ruderal and semi-natural vegetation types significantly impacts the composition of a wall's flora (Duchoslav 2002). Additionally, existing species are affected by the wall's distinct zones, consisting of the vertical surface with joints, the top, and the base. Various plant species that may colonise such environments are influenced by the artificial genesis of urban landscapes and wall-building technologies (Duchoslav 2002). There is a need to characterise the plant species distribution as well as their composition present in these areas in order to more effectively comprehend and handle the walls, protect them, and improve the environmental benefits of their associated habitats since it has been observed that numerous species of plants grow on the vertical surface of walls in urban areas. The analysis of the wall flora aids in developing an understanding of urban landscapes (Francis 2011) and is particularly crucial for maintaining historical sites.

Whether native or non-native, the plants that sprout out on their own in cities provide crucial ecological purposes. These activities are referred by ecologists as "environmental services," which involve additional absorption of nutrients in wetlands, food and medicine, soil erosion control, air, water, and soil pollution tolerance, and heat reduction in paved areas. Lichens and mosses are indicators of the water-nutrient component of the wall ecology. Plants, such as shrubs, herbs, and seedlings, depend on the effects of water-nutrient availability and habitat interaction. At the same time, the tree exhibits dependence on the larger-scale habitat components. Natural ecosystems that are spatially persistent ensure that there are always sufficient sources of seed, water, nutrients, a favourable microclimate, and clean air to support the establishment of wall vegetation (Jim et al 2010). The plant colonisation of walls is highly dependent on the presence of diaspores from the nearby semi-natural vegetation. Many studies have been done to investigate the wall flora in India, but there are few studies done in the humid tropical region. For instance, in India, some studies have been done, such as the vegetation of Bankura District (West Bengal) (Ghosh and Das 2002) and the vascular wall flora of Varanasi city (Uttar Pradesh) (Singh et al 2014). Studies on wall flora have existed since earlier times, but little is known about the vegetation that grows and inhabits Aligarh's urban walls. This research aims to survey and catalogue the diverse plant species naturally inhabiting these unique

habitats while also evaluating their distribution patterns in terms of frequency, diversity, and dominance. Furthermore, the study delves into the specific case of Aligarh District, one of India's ancient urban centres, to investigate how cracks and crevices in walls serve as nurturing grounds for plant growth. By observing the seasonal shifts in wall flora, the study seeks to shed light on the intricate interplay between urban environments and the natural world.

MATERIAL AND METHODS

Study area: The Aligarh District (latitudes 77°, 29°, and 78°, 38° east and 27°, 29° to 28°, 10° north) is situated in western Uttar Pradesh. It has a tropical monsoon climate with a wet season that includes two extreme weather events: bitterly cold winters and hot summers (Gulzar and Siddiqui 2015). In terms of geography, the district's low lying centre and uplands to the east and west give it the appearance of a shallow basin. Ninety-two percent (252.5 mm) of the total rainfall falls during the months of July, August, and September. Hence district is characterised by a monsoon-type climate. Mid-November marks the beginning of the winter season, which lasts until February. January is the coldest month of the year, with an average low of 15°C. October is regarded as a strictly transitional month. March marks the beginning of the summer season, which finishes in mid-June. In May and June, the average high temperature may reach 45 ℃. Aligarh's soil is primarily alluvial. Old alluvium (bangar/bhangar) is found above the flood levels of the rivers and their tributaries, whereas young alluvium (Khadar) is found in the river areas impaired by flooding (Khan et al 2018).

Field observation: A two-year comprehensive field survey was conducted to document the plant species growing on the walls in the Aligarh district from January 2021 to December 2022. Identification of these wall-adherent species was done using standard monographs and with the help of a taxonomic expert. After identification, nomenclature was updated following 'The World Flora Online' (https://www.worldfloraonline.org/), 'Tropicos' (http://www.tropicos.org/) and 'International Plant Name Index' (https://www.ipni.org/) (Table 1). The collected plant specimens have been deposited in the herbarium of the Botany Department of Aligarh Muslim University, Aligarh. The wall flora was studied in the different areas of Aligarh district, like Barauli, Atrauli, Harduaganj, Gonda, and Jalali (Fig. 2). Besides this, the wall flora was studied near the old buildings of main Aligarh city, such as the walls of buildings represented by residences, hospitals, educational and administrative buildings, canteens, motor garages, health centres, gymnasiums, forts, playgrounds, and churches. Every two months, there was one visit. Consequently, twelve trips in total were made for the field survey throughout the two-year period. The attempts were undertaken to search each and every corner of the Aligarh district throughout the survey procedure for wall flora.

RESULTS AND DISCUSSION

The city walls have changed over the course of civilization into specialised areas. Following the survey, it was discovered that the walls of the Aligarh district were home to 118 different species of vascular and non-vascular plants. There were 113 angiosperms (Table 1), three pteridophytes (Table 2), and two bryophytes (Table 3). Additionally, the angiosperms were given by 81 genera from 42 families, out of which 92 plant species were dicotyledons that are dispersed across 36 families, compared to 21 plant species with monocotyledons dispersed in 6 families. The study demonstrates that dicotyledonous species predominate the angiosperm flora of Aligarh city walls, with a more significant proportion than monocotyledonous ones. Additionally, three species of pteridophytes and two species of bryophytes distributed among two families of each group (Tables 2, 3). These families were each assigned locations based on the Bentham & Hooker classification. The Aligarh wall flora was predominately made up of an angiosperm group of plants, and no known gymnosperm species were found. Poaceae (15) and Asteraceae (12) families had the greatest number of species of plants documented on the city walls of Aligarh, followed by the Amaranthaceae family, which has 7 plant species recorded, (Fig. 3). The previous research study also shows the dominance of the Asteraceae and Poaceae families on the wall ecosystem (Pavlov and Tonkov 2005, Nedelcheva 2011, Singh 2011, Singh et al 2014).

The walls were colonised by the representative members of these three dominant families throughout three distinct seasons. Members of the Asteraceae often colonise the walls in the winter. In contrast, those of the Poaceae typically do so during the rainy months, while the members of Amaranthaceae colonise the walls mainly throughout the summer. In accordance with the study, only 11 (9.4%) plant species were discovered to exist during the summer season, whereas 31 (26.4%) and 37 (31.6%) plant species only exist during the rainy and winter seasons, respectively. Additionally, 1.7% of plant species exist in both the rainy and summer seasons as well as the winter and summer seasons, compared to 11 (9.4%) species that were discovered to live in both. However, 25 (21.3%) habitats for plants on walls are ideal for their appearance and growth throughout the winter and rainy seasons. Furthermore, it is evident from the study that the rainy season supports many plant species connected to walls. The annual plants (41%) were greater in number among other life span forms, followed by perennials (40%).

Table 1. Angiospermic wall flora of Aligarh district, India

Plant species	Family	Habit	Seasonal occurence	Origin status	Life forms	Accession No.
Tinospora cordifolia (Willd.) Miers	Menispermaceae	Herb	Rainy	Native	Therophyte	31337
Argemone mexicana L.	Papavaraceae	Herb	Winter	Exotic	Therophyte	31221
Fumaria indica (Hussk.) Puglesly	Fumaraceae	Herb	Winter	Native	Chamaephyte	31575
Brassica rapa L.	Brassicaceae	Herb	Winter	Exotic	Therophyte	31121
Lepidium didymum L.	Brassicaceae	Herb	Winter	Exotic	Chamaephyte	31135
Sisiumbrium irio L.	Brassicaceae	Herb	Winter	Native	Therophyte	31192
Portulaca oleracea L.	Portulacaceae	Herb	Winter	Exotic	Chamaephyte	31291
Portulaca grandiflora Hook.	Portulacaceae	Herb	Winter	Exotic	Therophyte	31928
Stellaria media (L.) Vill.	Caryophyllaceae	Herb	Winter	Native	Therophyte	3104
Bombax ceiba Burm. F.	Malvaceae	Tree	Rain, Winter & Summer	Native	Phanerophyte	31457
Malvastrum coromandelianum (L.) Garcke	Malvaceae	Undershrub	Rainy	Exotic	Therophyte	31303
Sida rhombifolia L.	Malvaceae	Undershrub	Rainy	Exotic	Therophyte	31438
Urena lobata L.	Malvaceae	Undershrub	Rainy	Exotic	Therophyte	31405
Ziziphus nummularia (Burm.f.) Wt. & Arn.	Rhamnaceae	Shrub	Rainy,Winter & Summer	Native	Phanerophyte	31463
Biophytum sensitivum DC.	Oxalidaceae	Herb	Winter	Native	Therophyte	31460
Oxalis corniculata L.	Oxalidaceae	Herb	Rainy	Exotic	Chamaephyte	31965
Azadirachta indica A. Juss.	Meliaceae	Tree	Rainy,Winter & Summer	Native	Phanerophyte	31994
Melia azedarach L.	Meliaceae	Tree	Rainy, Winter & Summer	Native	Phanerophyte	31453
Melilotus indicus (L.) All	Fabaceae	Herb	Winter	Native	Chamaephyte	31503
Melilotus officinaliss (L.) Pall.	Fabaceae	Herb	Winter	Exotic	Chamaephyte	31541
Trifolium alexandrium L.	Fabaceae	Herb	Winter	Exotic	Phanerophyte	31504
Cassia tora L.	Ceaslpiniaceae	Herb	Winter & Rainy	Exotic	Therophyte	31402
Leucaena leucocephala (Lam.) de Wit	Ceaslpiniaceae	Tree	Rainy, Winter & Summer	Exotic	Phanerophyte	31982
Lablab purpureus (L.) Sweet	Ceaslpiniaceae	Herb	Winter & Summer	Exotic	Phanerophyte	31912
Citrullus lanatus (Thunb.) Matsum. & Nakai	Cucurbitaceae	Herb	Rainy	Exotic	Therophyte	31924
Coccinia grandis (L.) Voigt.	Cucurbitaceae	Herb	Winter & Summer	Native	Therophyte	31506
Trianthema Portulacastrum L.	Aizoaceae	Herb	Summer	Exotic	Therophyte	31506
Eucalyptus hybrida Maiden	Myrtaceae	Tree	Rainy, Winter & Summer	Exotic	Phanerophyte	31493
Oldenlandia corymbosa L.	Rubiaceae	Herb	Winter	Native	Therophyte	31448
Ageratum conyzoides L.	Asteraceae	Herb	Summer	Exotic	Therophyte	31559
Bidens Pilosa L.	Asteraceae	Herb	Winter	Exotic	Therophyte	31529
Blumea eriantha DC.	Asteraceae	Herb	Summer	Native	Therophyte	31216
Blumea lacera DC.	Asteraceae	Herb	Rainy	Native	Therophyte	31342
Calandula officinalis L.	Asteraceae	Herb	Winter	Native	Therophyte	31273
Erigeron bonariensis L.	Asteraceae	Herb	Summer & Rainy	Exotic	Therophyte	31591
Eclipta alba Hassk.	Asteraceae	Herb	Rainy	Native	Therophyte	31369
Gnaphalium purpureum L.	Asteraceae	Herb	Winter	Exotic	Therophyte	31219
Parthenium hysterophorus L.	Asteraceae	Herb	Winter & Rainy	Exotic	Therophyte	31217
Sonchus arvensis L.	Asteraceae	Herb	Winter	Exotic	Therophyte	31197

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Table 1. Angiospermic wall flora of Aligarh district, India

Plant species	Family	Habit	Seasonal occurence	Origin status	Life forms	Accession No.
Sonchus oleraceus L.	Asteraceae	Herb	Winter	Exotic	Therophyte	31198
Tagetes erecta L.	Asteraceae	Herb	Winter	Exotic	Therophyte	31219
Anagallis arvensis L.	Primulaceae	Herb	Winter	Exotic	Therophyte	31558
Catharanthus roseus G. Don	Apocynaceae	Herb	Rainy, Winter & Summer	Exotic	Therophyte	31414
Calotropis gigantea (L.) R. Br.	Asclepiadaceae	Shrub	Rainy, Winter & Summer	Native	Phanerophyte	31590
Calotropis procera (Ait.) R. Br.	Asclepiadaceae	Shrub	Rainy, Winter & Summer	Native	Phanerophyte	31311
Ipomea nil (L.) Roth.	Convolvulaceae	Herb	Summer	Exotic	Chamaephyte	31547
Evolvulus nummularius L.	Convolvulaceae	Herb	Rainy	Native	Chamaephyte	31591
Campsis grandiflora K.Schum.	Bignoniaceae	Tree	Summer	Exotic	Phanerophyte	31006
Datura metel L.	Solanaceae	Undershrub	Rainy & Winter	Exotic	Phanerophyte	31567
Datura stramonium L.	Solanaceae	Herb	Rainy	Exotic	Therophyte	31496
Nicotiana plumbaginifolia Viv.	Solanaceae	Herb	Winter	Exotic	Therophyte	31258
Solanum nigrum L.	Solanaceae	Herb	Winter	Native	Therophyte	31275
Solanum virginianum L.	Solanaceae	Herb	Rainy	Native	Therophyte	31427
Wethania somnifera (L.) Dunal	Solanaceae	Herb	Winter	Native	Therophyte	31319
Lindenbergia indica (L.) Kuntz	Scrophulariaceae	Herb	Rainy & Winter	Native	Therophyte	31276
Verbascum chinense (L.) Staut.	Scrophulariaceae	Herb	Winter	Exotic	Therophyte	31428
Veronica agrestis L.	Scrophulariaceae	Herb	Winter	Exotic	Therophyte	31568
Justicia japonica Thunb.	Acanthaceae	Herb	Winter	Exotic	Therophyte	31078
Ruellia tuberosa L.	Acanthaceae	Herb	Rainy & Summer	Exotic	Therophyte	31484
Rungia pectinata (L.) Nees	Acanthaceae	Herb	Winter	Native	Therophyte	31474
Lantana camara ((L.) R.W. Sanders	Verbenaceae	Shrub	Rainy,Winter & Summer	Exotic	Phanerophyte	31035
Hyptis suaveolens (L.) Poit.	Lamiaceae	Herb	Rainy	Native	Therophyte	31150
Ocimum amaricanum L.	Lamiaceae	Herb	Winter	Exotic	Therophyte	31138
Ocimum basilicum L.	Lamiaceae	Shrub	Rainy, Winter & Summer	Native	Therophyte	31550
Scoparia dulcis L.	Plantaginaceae	Herb	Summer	Native	Therophyte	31583
Rumex dentatus L.	Polygonaceae	Herb	Winter	Native	Therophyte	31066
Rumex crispus Linn.	Polygonaceae	Herb	Rainy	Native	Therophyte	31079
Peperomia pellucida (L.) Kunth.	Piperaceae	Herb	Rainy	Exotic	Therophyte	31250
Achyranthes aspera L.	Amaranthaceae	Herb	Rainy,Winter & Summer	Native	Therophyte	31031
Alternanthera sessilis (L.) DC.	Amaranthaceae	Herb	Rainy,Winter & Summer	Exotic	Chamaephyte	31249
Amaranthus polygamous L.	Amaranthaceae	Herb	Summer	Native	Therophyte	31062
Amaranthus spinosus L.	Amaranthaceae	Herb	Rainy,Winter & Summer	Exotic	Therophyte	31049
Amaranthus viridis L.	Amaranthaceae	Herb	Summer	Native	Therophyte	31011
Celosia argentea L.	Amaranthaceae	Herb	Winter	Native	Therophyte	31532
Gomphrena celosioides Mart.	Amaranthaceae	Herb	Rainy, Winter & Summer	Exotic	Therophyte	31551
Chenopodium album L.	Chenopodiaceae	Herb	Winter	Exotic	Therophyte	31036
Chenopodium murale L.	Chenopodiaceae	Herb	Winter	Exotic	Therophyte	31032
Boerhavia diffusa L.	Nyctaginaceae	Herb	Rainy & Winter	Native	Chamaephyte	30309

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Table 1. Angiospermic wall flora of Aligarh district, India

Plant species	Family	Habit	Seasonal occurence	Origin status	Life forms	Accession No.
Ficus benghalensis L.	Moraceae	Tree	Rainy,Winter & Summer	Native	Phanerophyte	31323
Ficus racemosa Roxb.	Moraceae	Tree	Rainy,Winter & Summer	Exotic	Phanerophyte	31365
Ficus hispida L. f.	Moraceae	Tree	Rainy,Winter &Summer	Native	Phanerophyte	31278
Ficus infectoria Roxb.	Moraceae	Tree	Rainy,Winter &Summ	Native	Phanerophyte	31349
Ficus religiosa L.	Moraceae	Tree	Rainy,Winter & Summer	Native	Phanerophyte	31322
Ficus carica L.	Moraceae	Tree	Rainy, Winter & Summer	Native	Phanerophyte	31515
Morus alba L.	Moraceae	Tree	Rainy,Winter & Summer	Exotic	Phanerophyte	31259
Holoptelea integrifolia Roxb.	Ulmaceae	Tree	Rainy,Winter & Summer	Native	Phanerophyte	31325
Cannabis sativa L.	Cannabaceae	Herb	Rainy	Exotic	Therophyte	31383
Acalypha indica L.	Euphorbiaceae	Herb	Rainy	Native	Therophyte	31564
Croton bonplandianum Baill.	Euphorbiaceae	Herb	Summer	Exotic	Therophyte	31364
Euphorbia hirta L.	Euphorbiaceae	Herb	Rainy & Winter	Exotic	Therophyte	31412
Euphorbia thymifolia L.	Euphorbiaceae	Herb	Rainy & Winter	Exotic	Therophyte	31001
Phyllanthus niruri Webst.	Euphorbiaceae	Herb	Rainy & Winter	Native	Therophyte	31535
MONOCTYLEDONS						
Zephyranthes sulphurea L.	Amaryllidaceae	Herb	Summer	Native	Therophyte	31150
Monstera gigantea Roxb.	Araceae	Shrub	Rainy,Winter & Summer	Native	Therophyte	31009
Sagittaria sagittifolia Linn.	Alismataceae	Herb	Rainy	Native	Therophyte	31017
Commelina benghalensis L.	Commelinaceae	Herb	Rainy	Native	Therophyte	31101
Cyperus rotendus L.	Cyperaceae	Herb	Rainy	Native	Therophyte	31168
Cyperus iria L.	Cyperaceae	Herb	Rainy	Native	Therophyte	31110
Brachiaria ramosa (L.) Stapf	Poaceae	Herb	Rainy	Exotic	Therophyte	31166
Chloris virgata Sw	Poaceae	Herb	Rainy & Winter	Exotic	Therophyte	31067
Cynodon dactylon (L.) Pers.	Poaceae	Herb	Rainy, Winter & Summer	Exotic	Hemicryptophyte	31002
Dactyloctenium aegyptium (L.) Willd	Poaceae	Herb	Rainy	Native	Hemicryptophyte	31155
Dichanthium annulatum Stapf.	Poaceae	Herb	Rainy	Native	Cryptophyte	31086
Digitaria ciliaris (Retz.) Koeler	Poaceae	Herb	Rainy	Native	Therophyte	31144
Digitaria setigera Roth	Poaceae	Herb	Rainy	Native	Therophyte	31071
Echinochloa colona (L.) Link	Poaceae	Herb	Rainy	Native	Therophyte	31103
Eleusine indica (L.) Gaertn.	Poaceae	Herb	Summer	Native	Chemaephyte	31141
Eragrostis amabilis ((L.) Wight & Arn.	Poaceae	Herb	Rainy	Exotic	Therophyte	31134
Eragrostis minor Host	Poaceae	Herb	Rainy	Native	Therophyte	31041
Oplismenus burmannii Beauv.	Poaceae	Herb	Rainy	Exotic	Chamaephyte	31028
Phalaris minor Retz.	Poaceae	Herb	Winter	Native	Therophyte	31162
Poa annua L.	Poaceae	Herb	Winter	Exotic	Therophyte	31037
Setaria verticillata (L.) P.Beauv.	Poaceae	Herb	Rainy	Exotic	Therophyte	31064

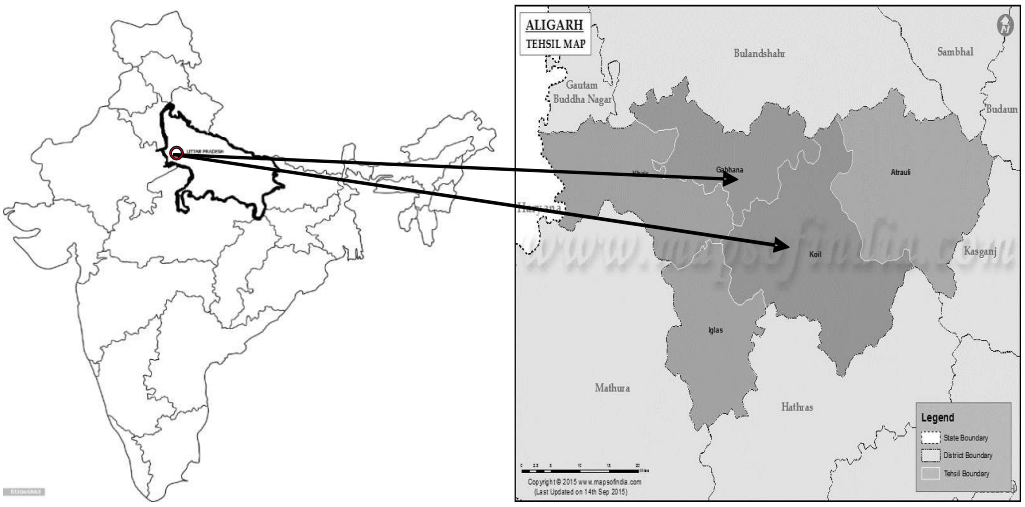


Fig. 1. Map of India showing Aligarh District (Uttar Pradesh)

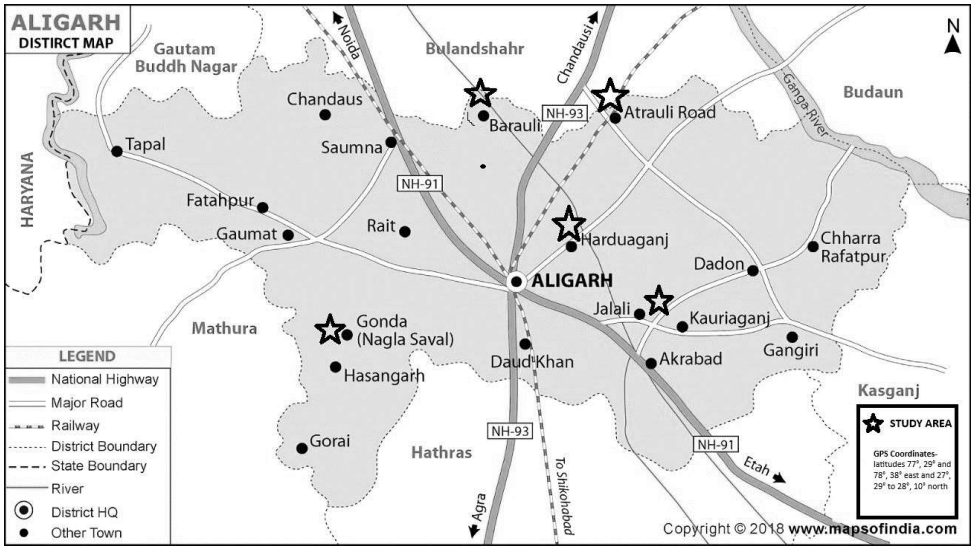


Fig. 2. Site location in relation to important landmarks

Table 2. Pteridophytic wall flora of Aligarh district, India

Plant species	Family	Habit	Seasonal occurrence	Origin status	Life forms	Accession No.
Adiantum philippense L.	Pteridaceae	Herb	Rainy & Winter	Native	Cryptophyte	316
Pteris vittata L.	Pteridaceae	Herb	Rainy & Winter	Exotic	Cryptophyte	317
Nephrolepis biserrata (Sw.) Schott.	Nephrolepidaceae	Herb	Rainy & Winter	Native	Cryptophyte	318

Table 3. Bryophytes wall flora of Aligarh district, India

Plant species	Family	Habit	Seasonal occurrence	Origin status	Life form
Marchantia polymorpha L.	Marchantiaceae	Herb	Rainy	Native	Cryptophyte
Funaria hygrometrica Hedw.	Funariaceae	Herb	Rainy	Native	Cryptophyte

Based on the research on origin status, out of the total documented species, 59 (50.4%) were native and 58 (49.5%) were exotic; there were just as many native species as exotic species. On the base and vertical wall surfaces, native species are more prevalent, although alien plants can easily occupy the roofs and tops of the walls. The studies on invasion ecology showed that disturbed habitats were populated by a small number of species, including *L. camara, M. micrantha*, *C. odorata*, and *A. conyzoides,* which led to a reduction in the richness of species (Sakachep et al 2021). The herbaceous 93 (79.4%) life forms were dominant in the total plant species recorded, followed by 14 (11.9%) trees, 6 (5.1%) shrubs, and 4 (3.4%) undershrubs.

The wall flora of Aligarh city is mainly populated by herbaceous plants. The wall flora also indicates that herbaceous plants predominate over other habit patterns (Pavlova and Tonkov 2005, Dos Reis et al 2006, Nedelcheva 2011, Singh 2011, Singh et al 2014). Additionally, herbaceous plants are better adapted to grow on walls in comparison with shrubs and trees. The study on life forms suggests the dominance of therophytes (66%) followed by phanerophytes (18%) and chameophytes (10%) in the wall flora of Aligarh District (Fig. 4), both cryptophytes and hemicryptophytes were also found. The plant species grow in different seasons, such as winter, summer, rainy, and all seasons. The maximum number of plant species were during the rainy (30.7%), season followed by winter (28.2%) (Fig. 5).

The vegetation that grows on city walls is an area of urban

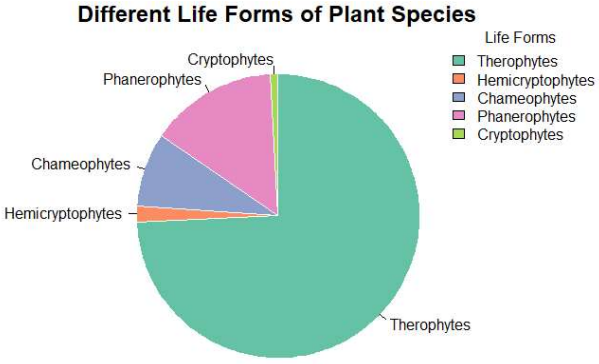


Fig. 4. Contribution by different life forms in wall flora

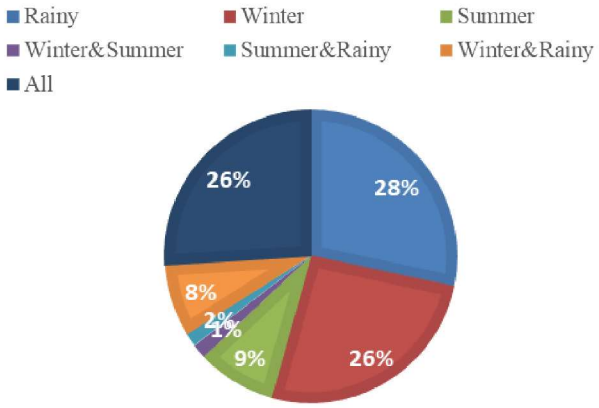


Fig. 5. Percent contribution by plant species growing in different seasons

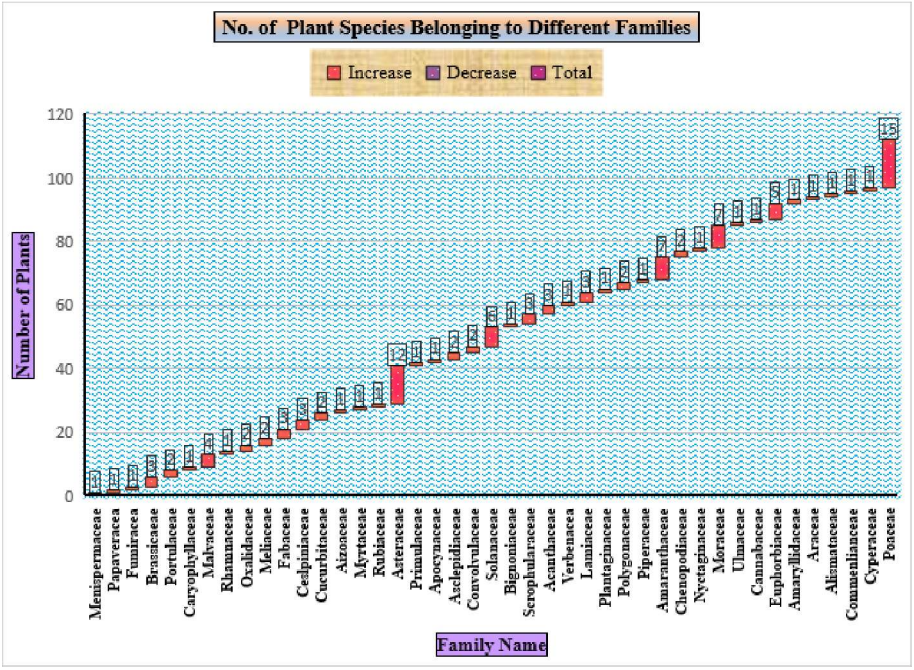
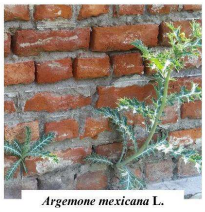
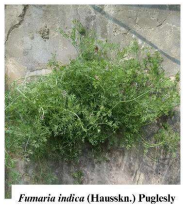


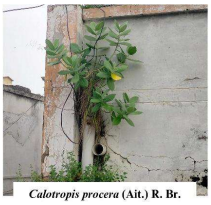
Fig. 3. Number of plants belonging to different families

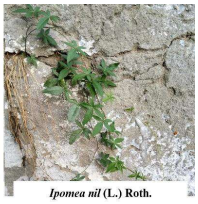

Tinospora cordifolia (Willd.) Miers


Argemone mexicana L.


Fumaria indica (Hausskn.) Puglesly


Catharanthus roseus G. Don

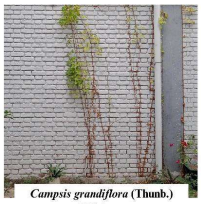

Calotropis procera (Ait.) R. Br.


Ipomea nil (L.) Roth.

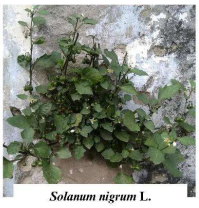

Brassica rapa L.

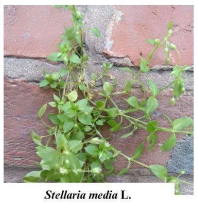

Lepidiun didymum L.

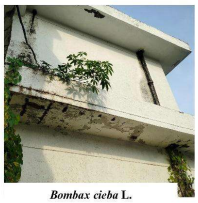

Portulaca oleracea L.

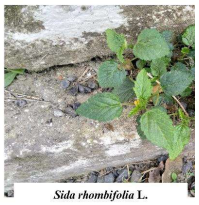

Campsis grandiflora (Thunb.) K.Schum

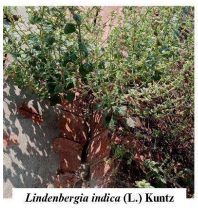

Nicotiana plumbaginifolia Viv.


Solanum nigrum L.

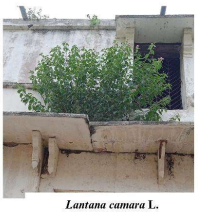

Stellaria media L.

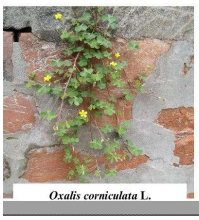

Bombax ceiba L.

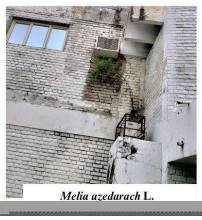

Sida rhombifolia L.

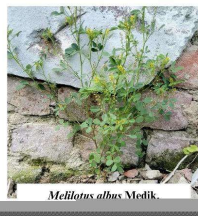

Lindenbergia indica (L.) Kuntz

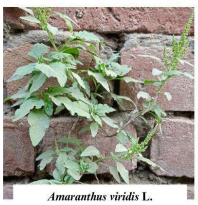

Veronica agrestis L.

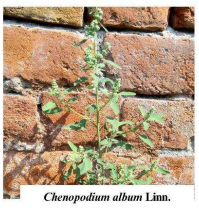

Lantana camara L.

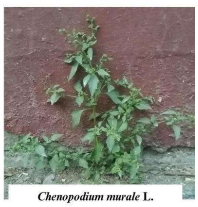

Oxalis corniculata L.


Melia azedarach L.


Melilotus albus Medik.


Amaranthus viridis L.


Chenopodium album Linn.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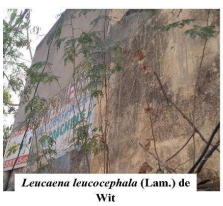
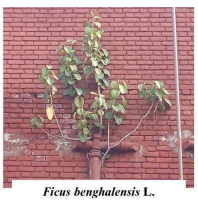

Leucaena leucocephala (Lam.) de Wit


Citrullus lanatus (Thunb.) Matsum. & Nakai


Coccinia grandis (L.) Voigt.


Boerhavia diffusa L.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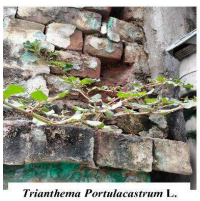
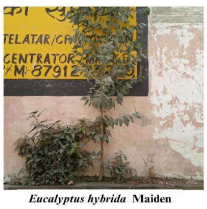
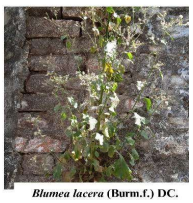
Ficus virens Aiton


Trianthema Portulacastrum L.

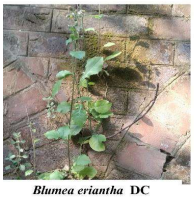

Eucalyptus hybrida Maiden


Blumea lacera (Burm.f.) DC.


Ficus carica L.

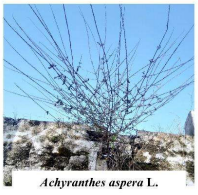

Ficus religiosa L.


Ficus racemosa Roxb.


Blumea eriantha DC


Calandula officinalis L.


Conyza bonariensis L.


Achyranthes aspera L.

Acalypha indica L.

Euphorbia hirta L.

Eclipta alba Hassk.

Gnaphalium purpureum L.

Sonchus oleraceus L.

Phyllanthus niruri Webst.

Achyranthes aspera L.

Holoptelea integrifolia *Roxb.*

Fig. 6. Selected photographs of the wall flora of Aligarh district

greenery that has received little attention but is crucial to the environment. Wall-adherent flora is a distinctive and overlooked urban plant that can survive in harsh conditions like soil and water scarcity, extreme heat, and pollution exposure. These plant communities have exhibited fantastic adaptability to the urban environment, which has allowed them to endure and add to the urban greenery. On a local, regional, and global level, the exponential rise of the human population and the ensuing rapid urbanisation in emerging nations like India promote natural and ecological system change processes (Roy et al 2020). Singh (2015) observed that prevalent woody plants found colonising the vertical wall surfaces of Varanasi city were *Ficus benghalensis, Ficus hispida, Ficus racemosa, Ficus religiosa, and Ficus virens*. Because of its rich biodiversity, it plays an important role in ecological services. A healthy and resilient urban environment requires understanding and commitment to preserving urban greenery, including the frequently ignored vegetation that adheres to walls. Studying the wall flora also essential for managing urban biodiversity and conservation efforts since it helps to manage natural resources in an ecologically sound manner while also providing habitat for wildlife (Roy et al 2020). Significant discoveries included the ecological importance of wall-adherent plants in maintaining urban wildlife, serving as pollinator pathways, and improving air quality. Thirteen significant ecosystem services, including managing urban temperature, air purification, and waste disposal, were identified in a study by Gómez-Baggethun (2013). The importance of the wall-adherent vegetation of Aligarh's urban greenery cannot be overstated. By offering crucial ecological niches for numerous organisms in the city, these green spaces contribute to the total urban biodiversity. The studied area was highly rich in biodiversity. Vegetation's ecological roles are essential for enhancing human welfare, protecting the environment, and reducing global warming. Studies on the ecological role of vegetation is highly valuable scientifically for managing vegetation in the future since land use and climate change are two major factors that affect how ecosystem services are provided (Yang et al 2019).

CONCLUSION

Aligarh district is made up of robust, adaptive, and well-equipped taxa that survive in harsh conditions as compared to other plants. Poaceae and Asteraceae family members were dominant during the rainy and winter seasons, respectively. The herbaceous life forms were dominant of the total plant species recorded; the most frequent woody plants are *Ficus benghalensis, Ficus racemosa, Ficus religiosa, Ficus virens, Bombax cieba, Lucaena lucocephala, Zizyphus numularis, Holoptelea intigrifolia, Lantana camara,* and *Calotropis procera* colonises the vertical wall surfaces of Aligarh District. The presence of a wide range of plant species, particularly woody perennials, atop Aligarh city walls demonstrates the city's age and low level of urbanization.

AUTHORS CONTRIBUTION

Mo Shadab, Nazish Akhtar, and Quratul Ain conducted the survey and wrote the manuscript. Mo Shadab, Mumayyza Khan and Nazish Akhtar performed statistical analysis. Mo Shadab and Uzma Parveen reviewed and edited the manuscript. M.B. Siddiqui designed and supervised the work.

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Seed Parameters, Oil Yield and Fatty Acid Profile of *Garcinia gummi-gutta* from Central Western Ghats, India

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***Abstract*:** The study conducted on *G. gummi-gutta* seeds collected from nine distinct locations across the Uttara Kannada district in Karnataka, a region situated within the central Western Ghats. The study employed the Soxhlet extraction method to determine the percentage of oil yield and utilized GC-MS analysis to assess the fatty acid composition. There were minimal statistical differences in seed characteristics and fatty acid profiles among the nine sites. The differences in oil yield across these sites did not demonstrate statistical significance. The study revealed highest of 46.64 percent oil yield from individual tree with an average of 39.32 percent overall. The seed oil extracted exhibited characteristics of being solid at room temperature and had an unpleasant flavour and fragrance, colours ranging from brown to creamy tones. GC-MS analysis identified the eight distinct fatty acids in the oil samples. Predominantly, oleic acid and stearic acid were found in all samples. Oleic acid ranged between 54.56 to 59.79 percent while stearic acid varied from 33.57 to 40.33 percent. The collective proportions of saturated and unsaturated fatty acids were at 60.15 percent and 39.85 percent, respectively.

***Keywords*:** *Garcinia gummi-gutta,* Seed parameters, Oil yield, Fatty acid profile, GC-MS

Garcinia gummi-gutta (L) Rob. (syn. *Garcinia cambogia*) known as Malabar Tamarind. It's a medium sized evergreen tree with average height of 20 m. Flowering starts January to March and fruits start to mature in June in India (Karthik and Ramana 2023). People usually collect the naturally dropped mature fruits, sometimes and also harvest the same manually from the tree. The seeds are not utilized most cases. The sharp sour tasting fruit rind traditionally used as flavoring agent in rural part of southern India and also as remedy to digestive disorders and intestinal parasites, rheumatism, bowel complaints (Semwal et al 2015). Apart from rind seeds are also used for various traditional purposes viz. moisturizer in winter, treating cracks, rashes and sometimes burn wounds, dehydration and diarrhea treatments (Mohammed et al 2017). Seeds oil is edible and usually ranges between 35 to 45 percent on average. The seed oil extracted has very good potential to be used in bio-diesel industries as a raw material (Subramani et al 2018). Various climatic and environmental factors can influence the growth and establishment of trees that could show great variance (Rangwala and Miller 2012). The study was aimed at recording the different parameters viz. seed parameters, oil yield and respective fatty acid composition from nine locations with different climatic and environmental conditions from central Western Ghats of Karnataka, India.

MATERIAL AND METHODS

Study area and collection of samples: The study was conducted in Uttara Kannada district of Karnataka, a part of Central Western Ghats, India. Nine sites were randomly selected. In each site 5 trees were chosen as replications. To maintain the homogeneity, trees in the 50–80 cm girth class were picked. Tree heights ranged from 13.7 to 16.8 m, and crown diameters ranged from 7.50 to 9.25 m (Table 1). Annual rainfall varied from 2300 to 4722 mm, and altitude ranged from 418.7 to 646.3 m. Samples were collected between July and August. The samples were immediately preserved in polythene bags and were taken to the experimental lab for further examinations.

Physical characteristics-Seed parameters: The fruit material was cut open to record number of seeds per fruit. The seed, in terms of the principal axial dimensions, that is (in cm and mm): length, thickness and width is measured using a Vernier caliper with an accuracy of 0.01 mm. These measurements were replicated three times to get mean values.

Extraction and Quantification Oil from *G. gummi-gutta* Seed Kernel

Oil extraction: The seeds were dried; dried kernels of 100 g from each tree was powdered using grinder. The sample were stored in an air-tight jar. Oil was extracted by Soxhlet extraction method using non-polar solvent (petroleum ether) in 40 to 60^{o}C temperatures.

Percentage yield of oil (w/w %): The amount of extracted oil was determined and percentage yield of the oil from each sample was calculated on the basis of weight by using following formula, expressed in w/w %:

$$\text{Percentage of oil yield} = \frac{\text{Weight of the oil}}{\text{Weight of the kernel}} \times 100$$

Chemical Characterization of Seed Oil

Methylation of sample: The reaction was done using a 50 mL shaking flask under 50°C on a reciprocal shaker. An equivalent quantity of 10 g of Garcinia oil was mixed with TL linked Fe_3O_4 nanoparticle, and thrice the quantity of methanol was added to the solution of 0.5 g. After the completion of the reaction process, the residual methanol content was distilled off completely with the help of an evaporator at 65°C under vacuum condition. The resulting *Garcinia gummi-gutta* methyl ester was then subjected to the GCMS analysis. (Subramani et al 2018).

Gas Chromatographic-Mass spectrometry analysis of oil: The Fatty acid composition of oil was determined by Gas Chromatography-Mass Spectrometry (GC-MS) technique using Shimadzu-GCMS (QP2020 NX) instrument. The GC-MS was equipped with a split injector and an ion-trap mass spectrometer detector with a fused-silica capillary column having a thickness of 1.00 µm, dimensions of 30m x 0.25mm (Agilent DB-5MS) and temperature ranges of 60 °C and 325 °C. The column temperature was programmed between 60 ºC and 250 ºC at a flow rate of 3.0 mL/min. The temperature of the injector and detector were at 250 °C and 200 °C respectively. Helium gas was used as a carrier gas at a flow rate of 46.3 cm/ sec. Components were identified by computer-aided matching of their spectra with spectra of known compounds from the NIST (National Institute of Standards and Technology, USA) libraries mass spectral databases. The compounds were quantified by the area normalization method without considering response factors. Relative amounts of individual components were calculated based on GC peak areas (Choppa et al 2015).

Data analysis: The data was analyzed using 'R'. Correlation matrix was visualized using "ggcorr" package.

RESULTS AND DISCUSSION

Seed parameters: Seeds are of brown to dark brown in colour and almost stretched bean shape of about 1.5 to 2 cm length and 0.5 to 0.7 cm breadth. With non-significant difference between the sites among majority of seed related parameters (Table 2), the average number of seeds per fruit of 5.87, fresh seed weight of 3.78 g, dry seed weight of 0.64 g, kernel weight of 0.33 g, seed length of 22.03 mm, seed breadth of 6.63 mm and seed thickness of 3.23 mm was observed in the study. Minor variations between seed traits viz. seed length and breadth along with weight of seed among different wild accessions of *G. gummi-gutta* are prevalent (Kavya et al 2016). The changes in the environment caused by latitude, altitude, rainfall, temperature, moisture, and other external factors to the soil and climate of the region where the seeds were grown, are taken into consideration as essential factors influencing the seed qualities (Singh et al 2019). Morphological variation in seed characters among the wild accession may also be because of broad adaptations of species to range of edaphic conditions (Jenner et al 2003).

Oil yield: Sites did not influence the Oil yield of *G. gummi-gutta* seeds (Table 2). The oil colour was brown to creamy white and has disagreeable odour and taste, oil becomes solid in room temperature. Ramesh and Sharanappa (2014) and George et al (2018) and Parthasarathy and Nandakishore (2014) also reported the similar findings on *G. gummi-gutta* seed oil colour and physical parameters. The average oil yield in all the sites combined was 39.32 per cent (w/w), whereas the highest of 46.64 per cent was observed in tree number thirty-eight from site S_8 (Table 3). Parthasarathy

Table 1. Geo-climatic information and tree parameters of study area

Site	Altitude (m)	Locations	Latitude	Longitude	Mean annual rainfall (mm)	Annual rainy days	Mean annual temperature (°C)	Tree height (m)	Girth (cm)	Crown diameter (m)
S_1	646.3	Huthgar	14° 42'14"	74° 75'97"	3800 - 4722	120	24	13.7	61.6	8.35
S_2	610.7	Nettikai	14° 41'85"	74° 76'05"	3800 - 4722	120	23	14.5	70.8	9.25
S_3	623.3	Halegadde	14° 45'22"	74° 70'55"	3800 - 4722	120	24	16.8	68.3	8.55
S_4	516.2	Ambadgar	14° 80'71"	74° 73'63"	2950 - 3667	100	25	17.7	73.2	8.40
S_5	508.9	Kotikoppa	14° 73'35"	74° 67'51"	2950 - 3667	100	25	16.7	72.9	8.20
S_6	522.7	Kaggundi	14° 72'66"	74° 70'23"	2950 - 3667	100	25	15.5	69.6	8.35
S_7	460.8	Nagalagar	14° 54'21"	74° 69'39"	2300 - 3263	95	27	14.4	68.5	7.55
S_8	437.8	Havinakodlu	14° 52'71"	74° 69'22"	2300 - 3263	95	27	14.4	62.0	7.50
S_9	418.7	Thotadakasige	14° 52'71"	74° 64'53"	2300 - 3263	95	27	15.9	68.8	8.25

et al. (2013) reported the highest seed oil yield of 47 per cent. Rahangdale et al (2014) stated the variability within the oil yield content is probably because of the variation in exclusive ecological conditions.

Fatty acid profile of *Garcinia gummi-gutta* seed oil: Eight different fatty acids were found through GC-MS analysis (Fig. 1) of oil sample from the nine sites. Fatty acids viz. Saturated fatty acids (Palmitic acid, Stearic acid, and Arachidic and Unsaturated fatty acids (Oleic acid, Linoleic acid, Linolenic acid, Gadoleic acid and 11- eicosanoic acid were found at the concentration of 39.85 and 60.15 percent respectively (Table 4). Oleic acid and stearic acid are found in major quantities, while, palmitic acid and linoleic acid in minor quantities. Arachidic acid, linolenic acid, gadoleic acid and 11-eicosanoic acid found in trace amounts. Patil et al (2016) reported that major fatty acid found was oleic acid in seed oil of *G. gummi-gutta*. Ajayi et al (2007) reported that predominant fatty acids in *Garcinia xanthocymus* was palmitic acid (48.5 %) and oleic acid (35 %). In study

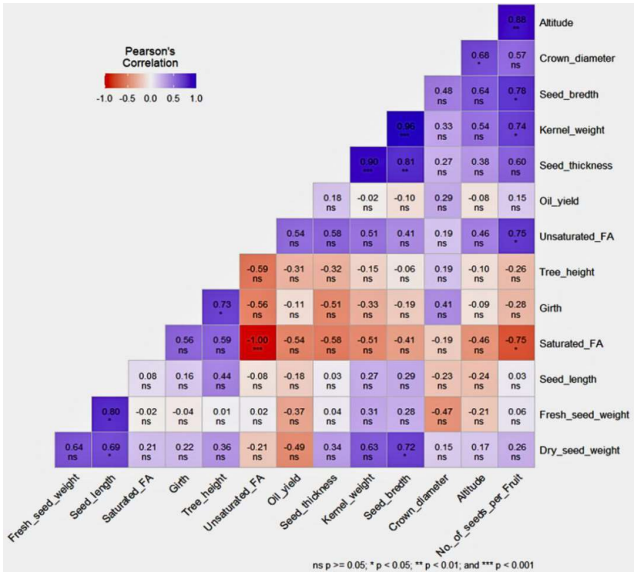

Fig. 2. Correlation heat map of site, tree, seed factors and fatty acid

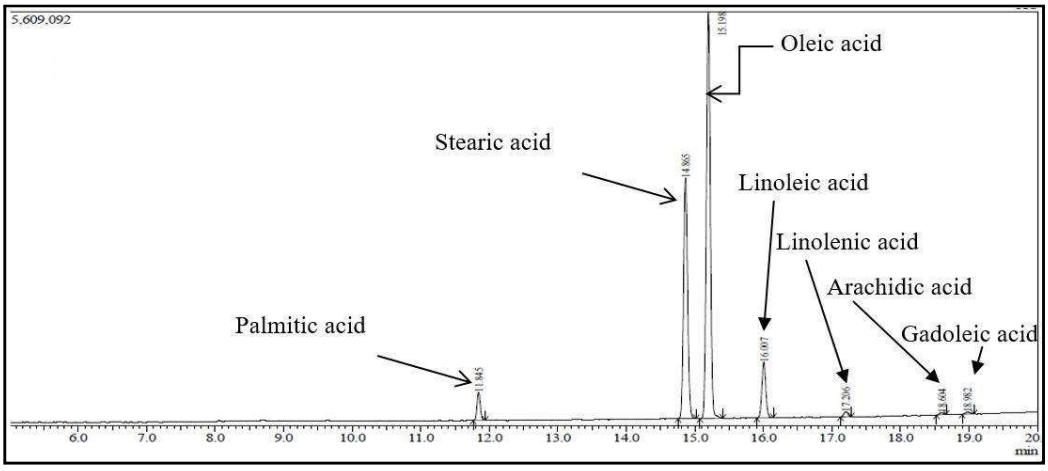

Fig. 1. Gas chromatogram of seed oil from the study site

Table 2. Seed parameters of study sites

Site	No. of seeds per fruit	Fresh seed weight (g)	Dry seed weight (g)	Kernel weight (g)	Seed length (mm)	Seed breadth (mm)	Seed thickness (mm)	Seed Oil Yield (%, w/w)
S_1	7.12 ^{a}	3.61 ^{cde}	0.60 ^{bc}	0.38 ^{a}	20.87 ^{c}	7.08 ^{a}	3.61 ^{a}	38.99 ^{a}
S_2	6.84 ^{ab}	3.14 ^{de}	0.61 ^{bc}	0.38 ^{a}	20.69 ^{c}	7.07 ^{a}	3.54 ^{a}	41.06 ^{a}
S_3	6.58 ^{ab}	3.34 ^{cde}	0.66 ^{bc}	0.43 ^{a}	21.69 ^{bc}	7.19 ^{a}	3.84 ^{a}	39.02 ^{a}
S_4	6.14 ^{bc}	5.14 ^{a}	0.84 ^{a}	0.37 ^{ab}	26.64 ^{a}	7.11 ^{a}	3.04 ^{a}	38.84 ^{a}
S_5	4.90 ^{d}	2.91 ^{e}	0.52 ^{bc}	0.15 ^{d}	20.47 ^{c}	5.47 ^{b}	1.84 ^{b}	38.78 ^{a}
S_6	5.46 ^{cd}	3.98 ^{bcd}	0.80 ^{a}	0.39 ^{a}	21.44 ^{bc}	7.16 ^{a}	3.60 ^{a}	37.90 ^{a}
S_7	5.42 ^{cd}	4.85 ^{ab}	0.58 ^{bc}	0.29 ^{bc}	22.11 ^{bc}	6.07 ^{ab}	2.84 ^{ab}	39.07 ^{a}
S_8	5.48 ^{cd}	4.31 ^{abc}	0.63 ^{bc}	0.35 ^{ab}	23.31 ^{bc}	6.55 ^{ab}	3.48 ^{a}	39.93 ^{a}
S_9	4.92 ^{d}	2.70 ^{e}	0.51 ^{c}	0.26 ^{c}	21.03 ^{c}	5.97 ^{ab}	3.28 ^{a}	40.33 ^{a}
Mean	5.87	3.78	0.64	0.33	22.03	6.63	3.23	39.32

1. Groups sharing the same letter (e.g., 'a') are not significantly different from each other.
2. Different letters (e.g., 'a' vs. 'b') indicate significant differences between the means of those respective groups.
3. The larger the differences in letters, the greater the significance of the contrast between the groups.

Table 3. Average seed oil yield percent of individual trees from the respective sites

Site	Tree number	Oil yield (%, w/w)	Average oil yield of site
S_1	T_1	39.70	38.99
	T_2	39.99	
	T_3	37.25	
	T_4	40.04	
	T_5	37.98	
S_2	T_6	39.27	41.06
	T_7	34.94	
	T_8	44.00	
	T_9	41.12	
	T_{10}	45.96	
S_3	T_{11}	39.67	39.02
	T_{12}	39.22	
	T_{13}	44.42	
	T_{14}	34.36	
	T_{15}	37.41	
S_4	T_{16}	39.90	38.84
	T_{17}	41.46	
	T_{18}	33.85	
	T_{19}	37.05	
	T_{20}	41.93	
S_5	T_{21}	37.02	38.78
	T_{22}	41.26	
	T_{23}	41.03	
	T_{24}	38.36	
	T_{25}	36.22	
S_6	T_{26}	42.75	37.90
	T_{27}	39.12	
	T_{28}	33.88	
	T_{29}	36.85	
	T_{30}	36.88	
S_7	T_{31}	45.09	39.07
	T_{32}	35.22	
	T_{33}	39.60	
	T_{34}	41.78	
	T_{35}	33.66	
S_8	T_{36}	33.67	39.93
	T_{37}	43.76	
	T_{38}	46.64	
	T_{39}	36.93	
	T_{40}	38.64	
S_9	T_{41}	40.14	40.33
	T_{42}	42.24	
	T_{43}	43.68	
	T_{44}	39.50	
	T_{45}	36.08	
Overall Mean		39.32	

There is no significant difference between the means of all sites

Table 4. Fatty acid profile of seed oil samples of *Garcinia gummi-gutta*

Fatty acids		Study sites									Mean
		S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	
Saturated	Palmitic acid ($C_{16}H_{32}O_2$)	3.08 ^{a}	2.91 ^{ab}	2.84 ^{bc}	2.83 ^{bc}	2.68 ^{cd}	2.52 ^{d}	3.01 ^{a}	2.13 ^{e}	3.05 ^{a}	2.78
	Stearic acid ($C_{18}H_{36}O_2$)	33.57 ^{f}	34.38 ^{e}	35.69 ^{d}	37.54 ^{b}	40.33 ^{a}	40.24 ^{a}	35.69 ^{d}	36.99 ^{c}	36.79 ^{c}	36.80
	Arachidic acid ($C_{20}H_{40}O_2$)	0.26 ^{cd}	0.28 ^{abcd}	0.35 ^{a}	0.33 ^{ab}	0.25 ^{d}	-	0.26 ^{bcd}	0.33 ^{ab}	0.33 ^{abc}	0.27
	Total (%)	36.91	37.57	38.88	40.7	43.26	42.76	38.96	39.45	40.16	39.85
Unsaturated	Oleic acid ($C_{18}H_{34}O_2$)	54.56 ^{g}	59.31 ^{b}	55.88 ^{ef}	57.43 ^{d}	55.43 ^{f}	55.98 ^{e}	59.79 ^{a}	59.23 ^{b}	58.55 ^{c}	57.35
	Linoleic acid ($C_{18}H_{32}O_2$)	7.45 ^{a}	2.07 ^{b}	1.84 ^{c}	1.48 ^{d}	1.30 ^{de}	1.25 ^{ef}	1.06 ^{fg}	0.96 ^{g}	1.04 ^{g}	2.05
	Linolenic acid ($C_{18}H_{30}O_2$)	0.72 ^{b}	0.63 ^{c}	3.15 ^{a}	0.13 ^{d}	-	-	-	-	-	0.52
	Gadoleic acid ($C_{20}H_{38}O_2$)	0.32 ^{a}	-	-	0.26 ^{b}	-	-	-	-	-	0.07
	11- Eicosenoic acid ($C_{20}H_{38}O_2$)	-	0.42 ^{a}	0.24 ^{c}	-	-	-	0.19 ^{c}	0.36 ^{b}	0.24 ^{c}	0.16
	Total (%)	63.09	62.43	61.11	59.3	56.73	57.23	61.04	60.55	59.83	60.15

Groups sharing the same letter (e.g., 'a') are not significantly different from each other
Different letters (e.g., 'a' vs. 'b') indicate significant differences between the means of those respective groups
The larger the differences in letters, the greater the significance of the contrast between the groups

unsaturated fatty acids seem to have strong positive correlation with number of seeds per fruit and positive correlation with altitude, seed kernel weight, seed breadth, seed thickness and percent oil yield. The saturated fatty acids were inversely proportional to the unsaturated fatty acids (Fig. 2). Oleic acid (mono-unsaturated, C18), is the maximum appropriate for proper biodiesel with 20 ºC melting point, very low viscosity, which makes it appropriate to be used below cold climatic conditions (Knothe 2008).

CONCLUSIONS

The observed differences in parameters across various sites did not exhibit significant variability or notable distinctions. The average oil yield from the seeds suggests that yield does not significantly differ between the trees, regardless of the location of collection. Eight fatty acids identified, five were unsaturated fatty acids and had the highest composition overall compared to the three saturated fatty acids. The fatty acid composition showed variation between sites and in some sites certain fatty acids were completely absent, to ascertain the reason for this kind of observation more research should be done on the aspect of biosynthesis of this kind fatty acids with respect to climatic and environmental conditions. One of the more significant challenges that was noted during the investigation is seed decortication, this step is very much necessary for proper use of seeds.

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Impact of Alien Invasive Species (*Lantana camara* L.) on Natural Regeneration and Soil Properties in Nagarahole Tiger Reserve, India

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***Abstract*:** *Lantana camara* L. is an alien invasive species widespread in India and is considered as a serious threat to native plant biodiversity and regeneration. The present study was carried out to assess the effect of lantana invasion on natural regeneration and soil properties in two different vegetation types of Nagarahole Tiger Reserve. Four levels of lantana infestation that were highly infested, moderately infested, lantana uprooted areas and areas without lantana infestation were considered for the present study. Five sub-quadrants were laid in the main quadrate to assess the regenerates. Four soil samples were randomly collected at 0-15 cm and 15- 30 cm depths and were analysed for different physicochemical properties. Highest density of regenerates was observed in uprooted areas followed by moderately infested areas in dry deciduous forests and in moist deciduous forest types, the highest density of regenerates was observed in non-infested areas followed by uprooted areas. Maximum soil moisture, bulk density, pH and electric conductivity were observed in highly infested areas but the organic carbon percentage and organic matter was highest in non-infested areas. The higher Lantana infestation is affected by natural regeneration and Lantana uprooting is helping to improve the regeneration status.

***Keywords*:** *Lantana camara*, Alien invasive, Diversity, Regeneration, Organic carbon

Tropical forests are well known for diverse terrestrial habitats harbouring rich biodiversity with the most significant living biomass on the other hand, these forests are under immense natural and anthropogenic pressures that have led to biodiversity loss. Invasive plant species are considered as the second most important threat to global biodiversity and habitat destruction (Bhatt et al 2011). The introduction and/or spread of alien invasive species beyond their native past or current range endangers biological diversity. Although not all imported species become invasive, they frequently become superior rivals for native species. When compared to native species, factors such as quick reproduction and development, phenotypic flexibility, strong dispersion capacity, and the ability to thrive on numerous food types and in a wide variety of environmental conditions are expected to aid in the spread of these invasives.

Lantana camara L. (Lantana) is a woody straggling shrub native to tropical America. It is listed by the Invasive Species Specialist Group as one of the 100 worst weeds in the world and has been brought into other nations as an ornamental or hedge plant. The plant is known as wild sage or red sage and belongs to the Verbenaceae family. The East India Company initially introduced it as an ornamental plant in the Royal Botanical Garden in Calcutta during 1807 and it quickly invaded throughout India, mostly in wastelands, railway tracts, and tropical woods. Reports of lantana's fast proliferation began to surface in numerous sections of the country in the early 20th century (Nagouchi and Kurniadie 2021). Lantana isa common invader of dry forest landscapes, slash-and-burn fallows and pasture lands all over India. It displays high morphological variation because of extensive breeding (Sharma et al 2005).

The Western Ghats in southern India are one of the world's twelve major biodiversity hotspots, with diverse fauna and flora. Lantana has spread throughout tropical forests, causing substantial harm by disrupting native plant variety and the nitrogen cycle process. *L. camara* has also expanded in practically all sections of Nagarahole Tiger Reserve, despite the fact that many efforts, such as hand removal and burning the invasive plant. However, it has developed its own process of infection, posing challenges to local ecological variety. With this background, the present study was carried out to through light on the effect of Lantana invasion on natural regeneration and soil properties in Nagarahole Tiger Reserve.

MATERIAL AND METHODS

Study site: The study was focused on the effect of infestation of *L. camara* on natural regeneration and soil properties in the Nagarahole Tiger reserve. It is a part of the Nilgiri biosphere

reserve, lies between the latitudes 11^0 58′ 25.75″ N and longitude 76^0 12′7.99″ E. The Nagarahole Tiger reserve was one of the best-managed parks in the country with the highest density of both herbivore and carnivore populations. The area receives 1000 to 1540 mm annual rainfall favours the area to have high humidity with a temperature ranging between 12°C and 32°C. Elevation of the park ranges from 687 to 960 m. The total geographical area of the reserve is 843.96 sq. km. located in the Kodagu and Mysore districts of Karnataka, India.

Selection of sample quadrates L: A preliminary survey was conducted to collect information about infestation level. Based on the preliminary survey, it was noticed that *L. camara* populations were found high in the dry deciduous and moist deciduous forests of the reserve which comes under southern tropical moist deciduous forests (sub group 3B type 3B/C3), southern tropical dry deciduous forests (group 5, subgroup 5A/C3) of Champion and Seth's classification (1968). Based on the cover of *L. camara*, infestation levels were grouped into different categories and a stratified random sampling technique was adopted with different levels of infestations as different strata. The quadrates having 60-80and 40-60%lantana cover was categorized as highly infested and moderately infested, areas with no lantana cover were considered as non-infested area and the areas where uprooting of lantana was done two years before was considered as uprooted area. In each stratum/category, 15 quadrates of 20 m ×20 m were laid randomly in both dry deciduous and moist deciduous forests. In each main quadrate, five sub quadrates of 2×2 m in four corners of the quadrate and one at the centre were laid to assess the regeneration status (Maheswarappa and Vasudeva 2018). All the regenerates within the subquadrate were botanically identified, and grouped under the regeneration classes for further analysis (Table 1).

In each of the main quadrates, four soil samples at 0-15 cm depth and 15-30 cm depth were collected randomly and the composite sample was prepared. The composite samples were dried at room temperature and were analyzed for pH, electric conductivity (EC), percentage of organic matter and available organic carbon by adopting standard procedures. For the canopy openness, observations were recorded at five locations within the plot and then the average of this observation was used for the calculation of the percentage of canopy openness.

Data analysis: The observation recorded during the field inventory was used to compute density of the regenerates, Importance value index, diversity parameters such as species richness, Shannon-Wiener index and Simpson's dominance index.All the data obtained were analysed using standard formulas with Microsoft excel (Version 2019).

Table 1. Regeneration classes

Classes	Plant description
Class I	0-40 cm height
Class II	>40-100 cm height
Class III	>100 cm height and ≤ 10 cm GBH
Class IV	>100 cm height and 10-30 cm GBH

RESULTS AND DISCUSSION

The density of regenerates was highest in the uprooted areas followed by moderately infested areas in dry deciduous forests. In moist deciduous forests, maximum density was observed in non-infested areas followed by uprooted areas. Natural regeneration was higher in uprooted and non-infested areas implies that natural regeneration decreased with higher lantana infestation. Mechanical uprooting is helping in improving natural regeneration of tree species (Table 2). Lantana invasion resulted in decrease in the recruitment of new individuals and recruitment of young tree individuals by successfully competing for space and light reported in Australia (Gooden et al 2009). The absence of lantana encourages the recruitment of new species. The areas highly infested with lantana showed very low regenerating individuals. Invasive species will suppress the regeneration of tree species thereby affecting native biodiversity (Litton et al 2006). Reduction in new recruitment in lantana-infested areas in the present study attributed to the dense cover created by vertical stratification of Lantana may reduce the intensity or duration of light under its canopy and thus decrease the herbaceous cover (Sharma and Raghubanshi 2015). *L. camara* and its allelopathic property may help the invasionof this species into non-native ranges also. Allelochemicals are probably released into therhizosphere of soil under its canopy and neighboring environments during the decomposition process of its residues and as leachates and volatile compounds from living plant partsof *L. camara*. Allelopathy plays a crucial role in the *L. camara* invasion and formation of monospecies stands (Nagouchi and Kurniadie 2021).

Table 2. Density (stems ha^{-1}) of regenerates under different levels of infestation

Infestation levels	Dry deciduous (stems ha^{-1})	Moist deciduous (stems ha^{-1})
Highly infested	655	715
Moderately infested	660	655
Non-infested	606	845
Uprooted	1121	740
CD (p=0.05)	217*	146

The regenerates in moderately infested regions had the highest species richness and diversity in dry deciduous woods. In the moist deciduous forests, maximum species richness was reported in highly infested regions followed by non-infested areas and greater diversity was in highly infested areas followed by non-infested areas as shown by Shannon's diversity index,the factors affecting species richness and diversity vary with geographical positions (Table 3).

Stohlgren et al (1999) reported that, conditions such as soil fertility were strongly correlated with both high native diversity and high invasive species diversity, implying that species-rich systems are not necessarily less invisible than species-poor systems. Buckley et al (2007) suggests that large-scale disturbances, such as forest fires, could drastically increase invader abundance. Dogra et al (2009) also reported that the decrease in the number of species will also affect the diversity of species within the invaded areas. Gooden et al (2009) demonstrated that the invasion of forest communities by woody plant invaders, like *L. camara*, draws significant adverse effects on native plant species diversity, both in terms of species richness and composition. The results of the present study are on par with Murali and Setty (2001) where the total number of species was highest in *L. Camara* infested plots in deciduous and scrub forests, while it is lowest in evergreen forests of Biligiri Rangan Hills. Sundaram (2011) stated that Lantana may not always suppress the growth of other species, it will more likely to grow in sites with more moisture that will also be preferred by many other species. Gooden et al (2009) found that species richness, diversity, evenness and population structure were negatively affected by increasing lantana density in south-eastern Australia. But sites where lantana was removed, has resulted in increased species richness and native species recruitment indicating an active management of the site. The number of regenerates dropped across all infestation levels as regeneration classes increased that is from seedling to sapling stage. The regeneration status in both the vegetation types followed a similar trajectory in all categories, with a typical inverse J shape curve suggesting normal regeneration. When compared to other degrees of infestation, uprooted regions and non-infested areas had a larger number of regenerates. The majority of regenerates came from regeneration class I, with the least regenerates from class IV (Fig. 1 & 2). Uprooted areas recorded maximum regenerates belonging to tree species compared to all other different levels of infestation in both locations. Population structure refers to the numerical distribution of individuals of different sizes or within a population at a given moment. Lantana flowers year-round can produce numerous seeds. An increase in light intensity and soil temperature stimulates the germination of the deposited seeds of lantana and that will lead to an increase in densities of lantana stems. Lantana may limit native tree species recruitment by competition for resources and its allelopathic nature (Gooden et al 2009). In the present study, the status of regeneration followed the similar trend in all the different levels of Lantana infestation in both the vegetation types following a normal inverse J shape curve indicating a normal regeneration trend. Uprooting of lantana was done two years before beginning of our study, regeneration was quite good in uprooted areas compared to the other three levels of infestation in dry deciduous vegetation type. Even though broadcasting of bamboo seeds has been done in moist deciduous forest, highest proportion of regenerating individuals were seen in non-infested areas. But the highest percentage of individuals belonging to class I was seen in uprooted areas, compared to all other infestation levels. It clearly indicates that, uprooting of lantana is encouraging new recruits.

The health of the forest is often indicated by the size class distribution of the community of plants. A reverse J-shaped curve for the size class distribution reflects a growing population, with a large proportion of seedlings and saplings (Sathish et al 2013). Sundaram (2011) reported that the size class structure of trees and shrubs in Biligiri Rangan Hills has changed over time with an increase in Lantana abundance

Table 3. Species richness and diversity of regenerates under different levels of Lantana infestation

Levels of Infestation		Highly infested	Moderately infested	Non-infested	Lantana uprooted
Evenness index	Moist deciduous	0.05	0.05	0.06	0.04
	Dry deciduous	0.10	0.10	0.12	0.11
Simpsons index	Moist deciduous	0.08	0.20	0.11	0.28
	Dry deciduous	0.20	0.12	0.19	0.33
Shannon's diversity index	Moist deciduous	2.85	2.07	2.58	1.61
	Dry deciduous	1.95	2.43	2.07	1.56
Species Richness	Moist deciduous	41	20	26	14
	Dry deciduous	19	24	18	14

between 1997 to 2008. Lantana invasion resulted in recruitment limitations of trees. Removal of Lantana encouraged regeneration of tree as well as shrubs compared to other infestation levels. *L. camara* inhibits native plant species recruitment by allelopathic interference of seed germination, seedling growth and survivorship. Sharma and Raghubanshi (2015) reported that in the wet sclerophyll forests of south-eastern Australia, non-invaded and managed sites showed significantly more fern, herb, tree and vine species than lantana invaded sites. Managed sites had significantly more herb and shrub species than either non-invaded or invaded sites. Shrub species richness was similar between non-invaded and invaded sites.

Canopy openness: The dry deciduous forest had the largest proportion of canopy openness, accounting for 78.43%, while the moist deciduous forest had the lowest percentage of canopy openness, accounting for 72.82%. The proportion of canopy openness and Lantana infestation has a favourable relationship (Table 4).

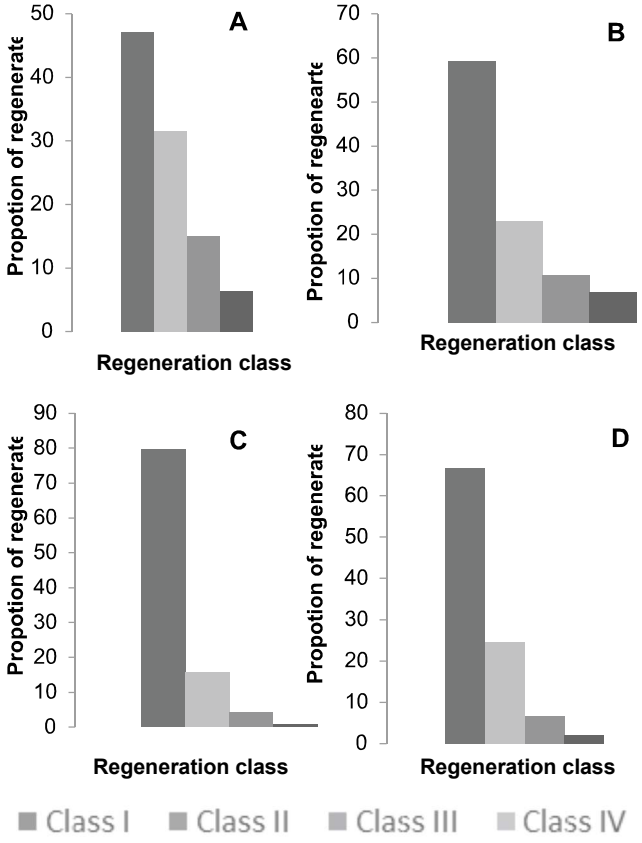

Fig. 1. Status of regeneration under different levels of infestation in dry deciduous forest (A: Highly infested, B: Moderately infested, C: Uprooted, D: Non-infested areas)

Parsons and Cuthbertson (2001) reported that Lantana showed more growth with increasing canopy openness and also the forest recovering from fire and logging was seriously affected by these invasive species. Lantana invasion increased with an increase in canopy openings and human interference (Totland et al 2005). Lantana cover is much higher in areas with low canopy cover. Chandrashekar and Swamy (2002) reported that light availability relatively enhances Lantana growth. Light has long been recognized

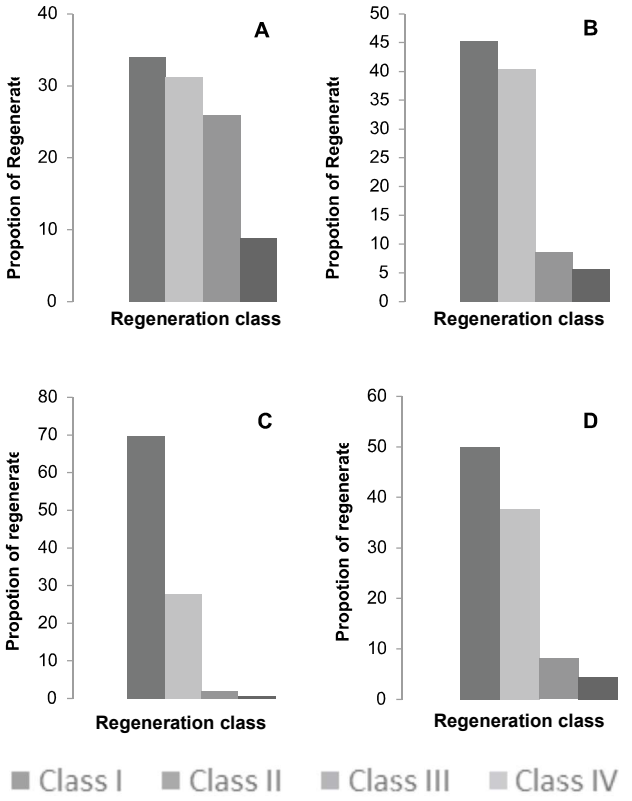

Fig. 2. Status of regeneration under different levels of infestation in moist deciduous forest (A: Highly infested, B: Moderately infested, C: Uprooted, D: Non-infested areas)

Table 4. Canopy openness (%) of dry deciduous and moist deciduous forest types

Infestation levels	Dry deciduous	Moist deciduous
Highly infested	77.70	72.82
Moderately infested	73.46	64.83
Non-infested	65.66	59.87
Uprooted	78.43	71.54
CD (p=0.05)	NS	7.771

as an important plant resource. Light availability on the forest floor has been recognized as a key factor that enhances inherent factors of inhabiting species to grow and spread. Totland et al (2005) reported that gap size and canopy openness are the factors that govern Lantana population size and reproduction. From Raizada et al (2009)study it is evident that Lantana cover was high in areas with a low native species canopy cover. Sundaram (2011) reported that canopy openness in the deciduous forest types of Biligi Rangan hills is encouraging the growth of lantana. Apart from this canopy openness, seed germination and seedling establishment rates of lantana increased with light availability and disturbance such as fire and understorey clearance. Tremendous propagule pressure, habitat heterogeneity and lantana seed sources are also playing role in enhancing the ecosystem invisibility.

Soil properties: Soil physicochemical properties varied significantly across locations as well as across different depths. The soil moisture content varied significantly among the different levels of infestation. The highest moisture content was recorded in a highly infested areas followed by a non-infested areas in both vegetation types. Sharma and Raghubanshi (2006) reported that *L. camara* biology promotes the accumulation of litter under the shrub, resulting in a buildup of organic carbon and nitrogen and can also hold water for a longer time.

Bulk density showed a significant difference across all the infestation levels. In moist deciduous forests, the non-infested area had more bulk density followed by highly infested areas, where the movement of wildlife will be high making the area more compact with less pore space. Contrasting to the expectation, in dry deciduous forest, the highly infested areas recorded more bulk density with less pore space.Debnath and Debnath (2018) observed no significant differences among invaded and non-invaded sites of *Chromolaena odorata.* The bulk densities were higher in all the three strata of *Chromolaena odorata* invaded sites of Atharamura forest of Tripura.

There was no significant difference in pH among the different vegetation types. In all the infestation levels pH was acidic ranging between 6-6.3 except for the highly infested areas of the dry deciduous forest where it had a neutral pH of 6.61-6.65. The higher soil pH was found in Lantana invaded sites compared to non-invaded sites (Osunkoya and Perrett 2010). Shackleton et al (2016) showed that the soils in Lantana invaded and uninvaded sites were generally acidic, with an average pH of 5.9 ± 0.1 in the *L. camara*-invaded sites and 5.6 in the natural sites, with no significant difference between the two sites of South Africa.

The electric conductivity varied significantly among different levels of infestation in dry deciduous forest. Highly infested as well as uprooted areas recorded the highest electric conductivity indicating high salinity in Lantana-infested areas.It indicates that, biology of Lantana will affect the soil's salinity, leading to an increase in the electric conductivity of soils. Osunkoya and Perrett (2010) also showed that no significant difference among Australia's Lantana invaded and non-invaded sites. Debnath and Debnath (2018) reported that soil conductivity was higher in both the non-invaded sites of lower and middle strata respectively while it is higher in invaded site of top strata of *Chromolaena odorata.*

The organic matter content of the soils differed significantly across locations and different infestation levels. Among different infestation levels, non-infested areas recorded the highest organic matter followed by uprooted areas. In dry deciduous forest, the highest percentage of organic matter was found in the non-infested areas followed by uprooted areas at 0-15 cm depth, whereas in 15-30 cm depth also, the maximum percentage of organic matter was observed in non-infested areas followed by uprooted areas. At 0-15 cm depth, the highest percentage of organic matter was recorded in the non-infested areas followed by uprooted areas. At 15-30 cm depth, the maximum percentage of the organic matter was recorded in the non-infested areas followed by the moderately infested areas in the moist deciduous forest. In both dry deciduous and moist deciduous forests, the non-infested areas recorded the highest percentage of organic matter.

The percentage of calculated organic carbon differed significantly across different levels of infestation in both locations. The highest organic carbon percentage was observed in the non-infested areas followed by uprooted areas. In the dry deciduous forest, the highest percentage of organic carbon was observed in the non-infested areas. Organic carbon is a derived parameter from organic matter and hence it showed a similar trend as that of organic matter (Table 5). Ehrenfeld (2003) documented both increase and decrease in organic carbon in exotic invasives. Invasives will modify soil carbon and nutrient pools but the direction and magnitude of the impacts were determined by the composition of the invasive species and soil properties. The role played by the secondary plant compounds of exotics in mediating changes in litter dynamics is completely unknown. The mechanisms causing these differences in decomposition, may include differences in size, degree and mode of vegetative spread, tissue chemistry and root distribution. The differences in litter mass or the litter decomposition rate are not always accompanied by changes in soil organic carbon dynamics.

Table 5. Soil parameters of both dry deciduous and moist deciduous forest types

Soil parameters	Infestation levels	Dry deciduous		Moist deciduous	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
Moisture content (%)	Highly infested	11.54	12.75	3.46	4.01
	Moderately infested	8.02	8.17	3.39	4.82
	Uprooted	8.11	8.69	2.84	3.15
	Non-infested	9.28	9.84	1.92	2.37
	CD (p=0.05)	2.33*	3.01*	1.26*	1.12*
Bulk density (g cc^{-1})	Highly infested	1.14	1.16	1.12	1.11
	Moderately infested	1.02	1.01	1.01	1.04
	Uprooted	0.92	0.92	1.08	1.13
	Non-infested	0.86	0.86	1.18	1.25
	CD (p=0.05)	0.13*	0.14*	0.12*	0.09*
Soil Ph	Highly infested	6.65	6.61	6.15	6.15
	Moderately infested	6.51	6.38	5.98	5.96
	Uprooted	6.46	6.57	6.03	6.21
	Non-infested	6.41	6.45	5.76	5.8
	CD (p=0.05)	0.24	0.32	0.34*	0.33
Electric conductivity (ds m^{-1})	Highly infested	0.18	0.17	0.11	0.1
	Moderately infested	0.09	0.09	0.12	0.09
	Uprooted	0.12	0.08	0.17	0.11
	Non-infested	0.1	0.1	0.14	0.13
	CD (p=0.05)	0.07*	0.05*	0.13	0.06
Organic matter (%)	Highly infested	5.15	5.06	4.46	4.4
	Moderately infested	3.7	3.12	4.52	4.52
	Uprooted	6.05	5.56	4.62	4.4
	Non-infested	6.15	5.8	4.65	4.57
	CD (p=0.05)	1.35*	1.53*	1.18	1.04
Organic carbon (%)	Highly infested	2.99	2.94	2.65	2.59
	Moderately infested	2.18	1.81	2.62	2.62
	Uprooted	3.51	3.23	2.68	2.55
	Non-infested	3.57	3.37	2.7	2.56
	CD (p=0.05)	0.78*	0.89*	0.68	0.6

*Soil properties are significant at the 0.05 level

CONCLUSION

Natural regeneration is being affected by the higher lantana infestation and uprooting is helping to improve the regeneration status. Higher canopy openings had higher lantana infestation. Maximum soil moisture content, bulk density, pH and electric conductivity were observed in highly infested areas but percentage of organic carbon and organic matter was highest in non-infested areas. The present investigation can be used as baseline data for future management of lantana with essential details about infestation of the species. Based on the present study, management plan can be made for removal of lantana through different ways in the future. Value addition of uprooted lantana can be taken up to improve the livelihood of local tribal communities. A long-term study can also be taken up to see the impacts of lantana and its removal on floristic diversity and regeneration over a time scale by establishing permanent plots.

AUTHORS CONTRIBUTION

HR Rashmitha - Involved in field data collection and data compilation. BN Sathish - Data collection, data analysis, and drafting the manuscript. D Mahesh Kumar - Helped in data collection, and writing of manuscript. C Harsha Kumar -

Provided the necessary permission for carrying out the research work and provided inputs for the manuscript. A Akshayakumari - Involved in field data collection, and data compilation.

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Effect of Altitudinal Gradation on Regeneration Status of NTFP Species in Central Western Ghats of Karnataka

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Abstract: The regeneration is the important criteria for the growth and survivability of forests and he current study was conducted to observed the regeneration status of NTFP species along altitudinal gradation in central Western ghats. Quadrate sample plot method was adopted for collection of data. the regeneration diversity of *Psychotria flavida* with an Important Value Index (IVI) value 22.8, *Knema attenuate* 23.52 and *Murraya paniculata* 8.81 was dominated in coastal, midghat and plane zone respectively, followed by *Hopea ponga* in Coastal and midghat zone and *Caryota urens* in Plane zone. In Family Importance Value (FIV) of Rubiaceae (33.60) recorded highest in coastal, Myristicaceae (19.50) in midghat zone and Rutaceae (16.57) in plane zone. Among the size class distribution for all the species in different altitudinal ranges, the decreasing trend of stems of lower size to higher size class exhibiting a reverse J-shape curve graph indicating promising growth of regenerating species.

Keywords: Regeneration, NTFP, Altitudinal gradation, Central Western Ghats, Size class distribution

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). There are millions of people living in and around the forests subsists on collections of non-timber forest products (NTFPs). Their livelihood is dependent on these forest resources (Prasad and Nageeb 2012). Successful regeneration of a species depends on the ability of seedlings and saplings to survive, grow and ability to initiate new seedlings. It is important step for achieving the long-term sustainability of forests (Saikia and Khan 2013). A successful regeneration perhaps indicated by sufficient number of seedlings, saplings and young trees in a given population (Pokhriyal et al 2010) and number of seedlings of any species can be considered as the regeneration potential of that species (Negi and Nautiyal 2005). The potential regenerative status of tree species depicts the composition of forests within a stand in space and time (Henle et al 2004). Natural regeneration is a central component for forest ecosystem dynamics (Getachew et al 2010) and is essential for preservation and maintenance of biodiversity (Rahman et al 2011). It is important to know the growth and development` status of species in the ecosystem and is a key parameter to determine ecosystem stability (Kadavul and Parthasarathy 2001; Deb and Sundriyal 2011). Plant regeneration studies are essential for advancing our knowledge of ecological processes, promoting sustainable practices in Western Ghat belt and addressing global challenges such as biodiversity loss, conservation issues of endangered species and climate change.

MATERIAL AND METHODS

The experiment was conducted in the Central Western Ghats of Uttara Kannada, two taluks of Uttara Kannada district namely Honnavara, Siddapura and Soraba in Shivamogga district. The study site falls under the administrative jurisdiction of Canara Forest Circle, represented by Siddapur Forest Range in the Sirsi territorial i.e. 14°23' N to 14°23'38"N and 74°48'E to 74'38"E. Forest Division, Kumta and Gersoppa forest ranges in the Honnavara territorial Forest Division. 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. The entire area was demarcated with the help of toposheet. 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 analysing vegetation composition of all types. Total of 60 sample plots were laid out to gather information on the regeneration of species. To assess the status of regeneration of species, within the 20 m × 20 m quadrates, two sub plots of size 5 × 5 m quadrates were laid out in two corners of the quadrate. Within the quadrates all the regenerating individuals were identified and

counted. For ease of counting, regenerating individuals were classified into following four classes based on their height and girth.

Class - I, = All individuals below 40 cm height

Class - II = All individuals between 40-100 cm height

Class - III = All individuals between and >100 cm height and <5 cm gbh

Class - IV = All the individuals between 5-10 cm gbh

Herbarium specimens were collected for species identification and the data were subjected to computation and analysis for results to know regeneration status across altitudinal gradient.

RESULTS AND DISCUSSION

Regeneration status of NTFP species: Coastal zone consists of 3277 individuals representing 91 species (Table 1). The number of individuals were maximum for *Psychotria flavida* (570 individuals ha^{-1}) followed by *Hopea ponga* ($^{-1}$) and *Knema attenuata* ha^{-1}) against a total number of individuals (3277 individuals ha^{-1}). Extent of frequency of seedlings of various species in coastal zone ranged between 2.5 to 52.5 per cent, *Hopea ponga* was most frequent species (52.5 %) followed by *Knema attenuata* (47.5 %) and *Psychotria flavida* (45 %). The importance value index of regenerates of seedlings for *Psychotria flavida* was (22.08) followed by *Hopea ponga* and *Knema attenuata.* Rawat et al (2018) also reported the higher seedling regeneration of *Evodia fraxinifolia, Lindera nacusua*, *Machilus duthiei*, *Viburnum nervosum* in the site lying in the lower altitudinal zone. The midghat zone consists of 2647 individuals representing 89 species (Table 2). The number of individuals was highest for *Knema attenuata* (419 individuals ha^{-1}) followed by *Hopea ponga* (ha^{-1}) and *Aglaia elaeagnoidea* ($^{-1}$) as against a total number of individuals (2647 individuals ha^{-1}). The frequency of seedlings of various species in ghat zone ranged between 2.5 to 87.5 per cent, *Knema attenuata* (87.5 %) was most frequent and abundant species followed by *Hopea ponga* (%). Importance value index of regenerates was a maximum for *Knema attenuata* (23.52) followed by *Hopea ponga*, *Aglaia elaeagnoidea* and *Garcinia gummigutta*. Higher values of percent frequency distribution associated with these species may be due to a greater number of matured trees in the midghat zone, which in turn might have resulted in higher amount of seed supply and consequently to better regeneration. Malik and Bhatt (2016) reported majority (27 - 56 %) of species showed good regeneration, a good percentage

Table 1. Regeneration diversity of NTFP species at coastal zone (0-250 m)

Rank	Species	No. of individual/ha	Rel. density	Frequency	Rel. frequency	IVI
1	*Psychotria flavida*	570	17.39	45	4.69	22.08
2	*Hopea ponga*	374	11.41	52.5	5.47	16.88
3	*Knema attenuate*	287	8.76	47.5	4.95	13.71
4	*Aporosa lindliyana*	231	7.05	42.5	4.43	11.48
5	*Uvaria narum*	187	5.71	35	3.65	9.35
6	*Ixora brachiata*	153	4.67	42.5	4.43	9.1
7	*Diospyros buxifolia*	132	4.03	30	3.13	7.15
8	*Calamus thwaitessi*	101	3.08	27.5	2.86	5.95
9	*Caryota urens*	79	2.41	30	3.13	5.54
10	*Memecylon umbellatum*	94	2.87	22.5	2.34	5.21
82	*Hydnocarpus pentendra*	1	0.03	2.5	0.26	0.29
83	*Madhuca longifolia*	1	0.03	2.5	0.26	0.29
84	*Persea macrantha*	1	0.03	2.5	0.26	0.29
85	*Stereospermum personatum*	1	0.03	2.5	0.26	0.29
86	*Strychnus wallichiana*	1	0.03	2.5	0.26	0.29
87	*Symplocos racemosus*	1	0.03	2.5	0.26	0.29
88	*Syzygium hemisphericun*	1	0.03	2.5	0.26	0.29
89	*Vateria indica*	1	0.03	2.5	0.26	0.29
90	*Zanthoxylum flavscens*	1	0.03	2.5	0.26	0.29
91	*Z. rhetsa*	1	0.03	2.5	0.26	0.29
	Total	3277	100	960	100	200

(19 - 45 %) registered poor regeneration while fair regeneration of by 7 - 30 per cent of species and new regeneration by 0 - 14 per cent. Plane zone consists of 2989 individuals representing 136 species (Table 3). The number of individuals was found to be highest for *Murraya paniculata* (197 individuals ha^{-1}) followed by *Caryota urens* (122 individuals ha^{-1}), *Aporosa lindliyana* and *Syzygium cumini* (102 individuals ha^{-1} each) as against a total number of individuals (2989 individuals ha^{-1}). The frequency of seedlings of various species in Plane zone ranged between 2.5 to 50 per cent *Caryota urens* is found to be most frequent species (50 %) followed by *Ixora brachiata* (40 %). In terms of the importance value index of regenerates of seedlings recorded for *Murraya paniculata* found to be highest (8.81) followed by *Caryota urens* and *Ixora brachiata* . The extent of regeneration was found to be inversely proportional to the altitude in the study area although exceptions were found to be associated with some sites with good microclimate condition. The increase in seedling density in the lower (0-250 m MSL) altitudinal zone may be due to land sliding effect which might have eroded with the soils of higher altitudinal zone and depositing it on the lower altitudinal zone. This might have increased the productive capacity of Coastal zone, which in turn might have supported the better seedling regeneration.

Regeneration status of NTFP families: Coastal zone exhibited a total of 39 families with 91 species (Table 4). Of the total number of individuals (3277 individuals ha^{-1}), the Rubiaceae recorded highest number of individuals (849) followed by Dipterocarpaceae and Myristicaceae . Rubiaceae family recorded highest number of species (7) followed by Lauraceae , Arecaceae and Rutaceae . The analysis of overall share of various families assessed in terms of family importance value, Rubiaceae family was most dominant (33.60) followed by Dipterocarpaceae and Arecaceae . The midghat zone exhibited a total of 41 families with 89 species. Of the total number of individuals (2647 individuals ha^{-1}) (Table 5). Myristicaceae recorded highest number of individuals (427) followed by Dipterocarpaceae (341) and Rubiaceae (289). Myrtaceae and Rutaceae were recorded highest number of species (7 species each) followed by Rubiaceae, Arecaceae and Lauraceae , Dipterocarpaceae and Annonaceae. In terms of the family importance value, Myristicaceae family found to be most dominant (19.50) followed by Rubiaceae (17.66) and Dipterocarpaceae (17.38). The plane zone consisted of 47 taxonomic groups. Of the total number of individuals (2989 individuals ha^{-1}) (Table 6). Rutaceae recorded highest number of individuals (277) followed by Rubiaceae and

Table 2. Regeneration diversity of NTFP species at midghat zone (251-500 m)

Rank	Species	No of individual/ha	Relative density	Frequency	Relative frequency	IVI
1	*Knema attenuate*	419	15.83	87.5	7.69	23.52
2	*Hopea ponga*	281	10.62	62.5	5.49	16.11
3	*Aglaia elaeagnoidea*	177	6.69	60	5.27	11.96
4	*Garcinia gummigutta*	155	5.86	65	5.71	11.57
5	*Ixora nigricans*	118	4.46	50	4.40	8.85
6	*Psychotria flavida*	120	4.53	22.5	1.98	6.51
7	*Garcinia Morella*	85	3.21	35	3.08	6.29
8	*Caryota urens*	66	2.49	40	3.52	6.01
9	*Neolitsea zelanica*	53	2	35	3.08	5.08
10	*Syzygium gardneri*	115	4.34	5	0.44	4.78
70	*Capparis heyneana*	1	0.04	2.5	0.22	0.26
81	*Cinnamomum macrocapum*	1	0.04	2.5	0.22	0.26
82	*Clausena indica*	1	0.04	2.5	0.22	0.26
83	*Elaeagnus conferta*	1	0.04	2.5	0.22	0.26
84	*Grewia umbellifera*	1	0.04	2.5	0.22	0.26
85	*Luvunga sarmentosa*	1	0.04	2.5	0.22	0.26
86	*Pinanga dicksonii*	1	0.04	2.5	0.22	0.26
87	*Syzygium cumini*	1	0.04	2.5	0.22	0.26
88	*S. jambos*	1	0.04	2.5	0.22	0.26
89	*Thottea siliquosa*	1	0.04	2.5	0.22	0.26
	Total	2647	100	1137.5	100	200

Table 3. Regeneration diversity of NTFP species at plane zone (501-750 m)

Rank.	Species	No of individual/ha	Relative density	Frequency	Rel frequency	IVI
1	*Murraya paniculata*	197	6.59	30	2.22	8.81
2	*Caryota urens*	122	4.08	50	3.7	7.79
3	*Ixora brachiata*	96	3.21	40	2.96	6.17
4	*Aporosa lindliyana*	102	3.41	35	2.59	6.01
5	*Garcinia gummigutta*	85	2.84	37.5	2.78	5.62
6	*Knema attenuate*	86	2.88	32.5	2.41	5.28
7	*Aglaia elaeagnoidea*	76	2.54	35	2.59	5.14
8	*Calycopteris floribunda*	101	3.38	22.5	1.67	5.05
9	*Syzygium cumini*	102	3.41	20	1.48	4.89
10	*Leea indica*	83	2.78	27.5	2.04	4.81
127	*Ficus hispida*	1	0.03	2.5	0.19	0.22
128	*Garcinia talboti*	1	0.03	2.5	0.19	0.22
129	*Gmelina arborea*	1	0.03	2.5	0.19	0.22
130	*Jasminum malabaricum*	1	0.03	2.5	0.19	0.22
131	*Madhuca latifolia*	1	0.03	2.5	0.19	0.22
132	*Mappia foetida*	1	0.03	2.5	0.19	0.22
133	*Memecylon terminale*	1	0.03	2.5	0.19	0.22
134	*Murraya exotica*	1	0.03	2.5	0.19	0.22
135	*Ochlandra species*	1	0.03	2.5	0.19	0.22
136	*Syzygium hemisphericun*	1	0.03	2.5	0.19	0.22
	Total	2989	100	1350	100	200

Table 4. Regenerating families of NTFP species at coastal zone (0-250 m)

Rank	Family	No. of individual/ha	No. of species	Relative density	Relative diversity	FIV
1	Rubiaceae	849	7	25.91	7.69	33.6
2	Dipterocarpaceae	375	2	11.44	2.2	13.64
3	Arecaceae	233	5	7.11	5.49	12.6
4	Euphorbiaceae	285	3	8.7	3.3	11.99
5	Annonaceae	283	3	8.64	3.3	11.93
6	Myristicaceae	292	2	8.91	2.2	11.11
7	Lauraceae	60	6	1.83	6.59	8.42
8	Rutaceae	37	5	1.13	5.49	6.62
9	Calophyllaceae	138	2	4.21	2.2	6.41
10	Ebenaceae	135	2	4.12	2.2	6.32
30	Sapindaceae	11	1	0.34	1.1	1.43
31	Piperaceae	10	1	0.31	1.1	1.4
32	Connaraceae	7	1	0.21	1.1	1.31
33	Ancistrocladaceae	6	1	0.18	1.1	1.28
34	Icacinaceae	6	1	0.18	1.1	1.28
35	Burseraceae	3	1	0.09	1.1	1.19
36	Achariaceae	1	1	0.03	1.1	1.13
37	Bignonaceae	1	1	0.03	1.1	1.13
38	Capparaceae	1	1	0.03	1.1	1.13
39	Symplocaceae	1	1	0.03	1.1	1.13
	Total	3277	91	100	100	200

Lauraceae . The family Rutaceae was most superior in terms of species composition (10 species) followed by Fabaceae and Rubiaceae. Among the families evaluated, Rutaceae superceded rest of the families in terms of FIV (16.57) followed by Rubiaceae and Lauraceae. In terms of the importance value index of regenerating diversity of seedlings recorded, *Knema attenuata* was highest in midghat zone (23.52) followed by lower altitudinal zone (Coastal zone) for *Psychotria flavida* and in the upper zone *Murraya paniculata*. However, least was in plane zone for *Syzygium hemisphericum* (0.22).

The evaluation of the components of diversity in three altitudinal zones revealed that the vegetation between 501 and 750 m MSL had higher family composition values (47 families), followed by the midghat zone between 250 and 500 m MSL (41 families), and the coastal zone between 251 and 500 m MSL (39 families) with the lowest values. Rahman et al (2011) also observed that regeneration frequency of both indigenous and exotic species was varied in five different habitats (forest, fallow land, homestead, roadside and others). Among these diversity of indigenous species was highest in forest (36 species), followed by roadside and fallow land while, diversity of exotic species was highest in roadside (12 species), followed by fallow land and forest and indicated that total of fifty-five species in forest had the highest number of species (43 species), followed by roadside (23 species), fallow land (16 species), and homestead (7 species in each). It may due to their different responses to environmental factors.

Size class distribution of regenerating layer: The status and population structure of regenerating individuals of different altitudinal ranges of NTFP species were assessed based on their size class distribution. The size class distribution for all the species in different altitudinal ranges, the decreasing trend of stems of lower size to higher size class exhibiting a reverse J-shape curve graph indicating promising growth of regenerating species {Fig. 1(d)}. In the Coastal zone highest stems were recorded in C-1 (1848) followed by 991, 256 and 182 stems in the size class C-2, C-3 and C-4 respectively which exhibited a reverse J-shape curve graph. Among the regenerating layer, 56.39 per cent of the individuals were occupied by Class-1 followed by Class-2, Class-3 and only 5.77 per cent of stems were in the Class-4 category. In the midghat zone highest stems were recorded in C-1 (1454) followed by C-2, C-3 and C-4 stems in the size class respectively which exhibited a reverse J-shape curve graph. Among the regenerating layer, 54.93 per cent of the individuals were occupied by Class-1 followed by Class-2 . Class-3 and only 5.89 per cent of stems were in the Class-4 category. In the plane zone highest number of individuals were in C-1 (1471) followed by 916, 341 and 261 stems in the size class C-2, C-3 and C-4 respectively which exhibited a reverse J-shape curve. Among the regenerating layer, 49.21 per cent of the individuals were occupied by Class-1 followed

Table 5. Regenerating families of NTFP species at midghat zone (251-500 m)

Rank	Family	No. of individual/ha	No. of species	Relative density	Relative diversity	FIV
1	Myristicaceae	427	3	16.13	3.37	19.5
2	Rubiaceae	289	6	10.92	6.74	17.66
3	Dipterocarpaceae	341	4	12.88	4.49	17.38
4	Myrtaceae	168	7	6.35	7.87	14.21
5	Meliaceae	266	3	10.05	3.37	13.42
6	Arecaceae	162	6	6.12	6.74	12.86
7	Clusiaceae	242	3	9.14	3.37	12.51
8	Rutaceae	78	7	2.95	7.87	10.81
9	Lauraceae	94	6	3.55	6.74	10.29
10	Melastomaceae	67	3	2.53	3.37	5.9
32	Achariaceae	2	1	0.08	1.12	1.2
33	Bignonaceae	2	1	0.08	1.12	1.2
34	Icacinaceae	2	1	0.08	1.12	1.2
35	Salicaceae	2	1	0.08	1.12	1.2
36	Aristolochiaceae	1	1	0.04	1.12	1.16
37	Asperagaceae	1	1	0.04	1.12	1.16
38	Capparaceae	1	1	0.04	1.12	1.16
39	Elaeagnaceae	1	1	0.04	1.12	1.16
40	Lamiaceae	1	1	0.04	1.12	1.16
41	Malvaceae	1	1	0.04	1.12	1.16
	Total	2647	89	100	100	200

by Class-2, Class-3 and only 8.73 per cent of stems were in the Class-4 category.

Based on the overall size class distribution of individuals coastal zone (0-250 m elevation) recorded highest (3277) number of individuals, this may be because of least disturbance in the inaccessible areas (Sharma et al 2017)

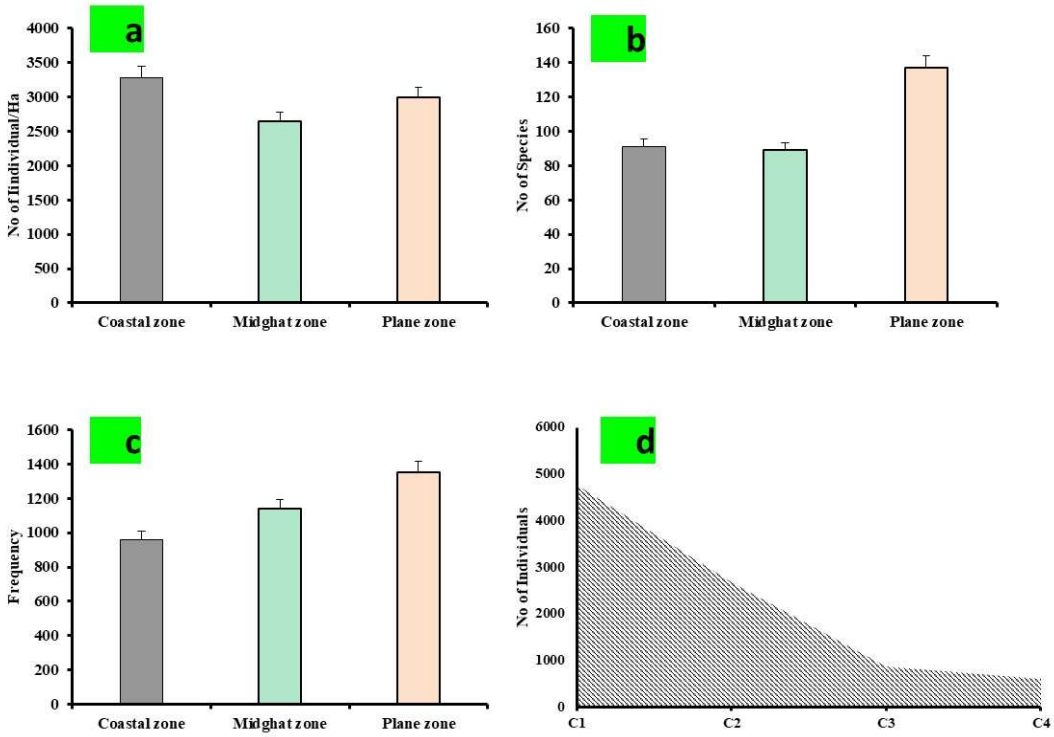

Fig. 1. Variation in Number of individuals per hectare, Number of species observed and Frequency in three altitudinal zones (i.e., a, b, c), Size class distribution of regenerates i.e., C1, C2, C3 and C4 (d)

Table 6. Regenerating families of NTFP species at plane zone (501-750 m)

Rank	Family	No. of individual/ha	No. of species	Relative density	Relative diversity	FIV
1	Rutaceae	277	10	9.27	7.3	16.57
2	Rubiaceae	218	8	7.29	5.84	13.13
3	Lauraceae	216	6	7.23	4.38	11.61
4	Fabaceae	149	9	4.98	6.57	11.55
5	Arecaceae	201	6	6.72	4.38	11.1
6	Combretaceae	150	7	5.02	5.11	10.13
7	Dipterocarpaceae	169	4	5.65	2.92	8.57
8	Euphorbiaceae	175	3	5.85	2.19	8.04
9	Clusiaceae	147	4	4.92	2.92	7.84
10	Myrtaceae	137	4	4.58	2.92	7.5
38	Bignonaceae	5	1	0.17	0.73	0.9
39	Pandanaceae	3	1	0.1	0.73	0.83
40	Annonaceae	2	1	0.07	0.73	0.8
41	Celastraceae	2	1	0.07	0.73	0.8
42	Piperaceae	2	1	0.07	0.73	0.8
43	Burseraceae	1	1	0.03	0.73	0.76
44	Capparaceae	1	1	0.03	0.73	0.76
45	Myrsinaceae	1	1	0.03	0.73	0.76
46	Oleaceae	1	1	0.03	0.73	0.76
47	Salicaceae	1	1	0.03	0.73	0.76
	Total	2989	137	100	100	200

followed by Plane zone (2989 individuals) and least in midghat zone (2647 individuals). This may be due to intensive biotic pressure on them. Collection of fruits or seeds by forest dwellers and tribals for selling as well as for subsistence without leaving fruit or seeds for natural regeneration are another important reason for the poor regeneration (Gunaga et al 2019). Similar observations were also recorded by Murthy et al (2016) and Pandey et al (2016). Rawat et al (2018) in Neora Valley National Park, West Bengal observed maximum individuals in lower dbh class of 10-20cm followed by 21-30cm, 31-40cm, but the least individuals were observed in the highest dbh. Lowest dbh class covered 50.7 percent of total individuals. The reverse J-shaped curve indicates that the forest is showing good regeneration capacity which is a good sign. Similar results were reported by Bharathi and Prasad (2015) in sacred groves of Western Ghats and Prasad and Bharathi (2016) in sacred groves of Virajpet.

CONCLUSION

The midghat zone is rich in regenerating capacity of NTFP species. The study provides useful information on the present condition of regeneration status of NTFP species along different altitudinal gradation. The present study highlights the lower elevational (Coastal zone) NTFP species had comparatively higher number of species, whereas lower number of species was recorded at higher elevational (plane zone) NTFP species, which imply the climatic adaptation by plant species. Altitude affect regeneration status as well as 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. Hence to reduce pressure on NTFP population, creating awareness among local peoples in harvesting techniques of NTFP species. The findings of present study provide a complete view of regeneration status in the study areas and possess a rich regeneration of NTFPs in the coastal zone.

AUTHORS CONTRIBUTION

Raviraj: Collection of field data and analysis of data, S. S. Inamati: Field analysis of data, M. R Jagadish: Field analysis of data and identification of NTFPs species, B. H. Ganesha.: Analysis of data and writing of manuscript, Rajath Kumar: Analysis of data and writing of manuscript

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Floristic Diversity and Vegetation Analysis of Heritage Langat Singh College, North Bihar, India

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***Abstract*:** Heritage campuses (including older universities/ college campuses) are home in urban areas for biodiversity study and conservation. Present study was undertaken to enumerate the natural plant diversity of one of the old heritage college of north Bihar; Langat Singh College, Muzaffarpur Bihar. On average of 91 plant species naturally including woody (trees), non-woody shrubs/herbs/grasses/ and ornamental plants has been identified. Species were analysed and its socio-economic aspects were also enumerated. Meliaceae and Fabaceae dominated the tree flora whereas *Poaceae* (grasses) dominated the non-woody flora. The tree species, viz. *Swietenia mahogani* and *Swietenia macrophylla (*Meliaceae) and *Cassia abbreviata* (Fabaceae) were most frequent and *Ficus benghalensis, F. religiosa*, *Phoenix dactylifera, Polyalthia longifolia* also thriving well. Out of total 91 species documented, 83 species representing 30 families are dicotyledonous while 13 species (6 families) are monocotyledonous. The most dominant dicot family is Fabaceae represented by maximum number of 10 species followed by Apocynaceae (7 species), Moraceae and Asteraceae represented by 6 species each. In monocot, majority of plants belongs to family Poaceae. The *Cycas revoluta* and *Dryopteris ludoviciana* are also recorded from campus.

***Keywords*:** Baseline data, Biodiversity, Conservation, Flora, Langat Singh College, Species diversity

To sustain biodiversity richness in urban ecosystems and rich diversified flora in urban cities may exist in different parks, botanical gardens, unused lands, urban forest or campus of old education Institutes. Educational institute/ campuses harboured high biodiversity and are a very informative and practical laboratory to perform floristic studies (Liu et al 2021). However, in India systematic review on the biodiversity of university/ college campuses is still lacking and confines to only few reports i.e.; flora of IISc. Bangalore (Suresh and Bhat 2000); B.H.U., Varanasi (Dubey 2004); Bharathiar university (Rajendran et al 2014), South campus B.H.U. Varanasi (Srivastava et al 2020), insert Fergusson College campus, Pune (Nerlekar et al 2016), Deccan College, Pune (Naik 2020), S.B.N Gov. PG College, Barwani (Sawle et al. 2022), Social Sciences Campus Rajagiri College, Kerala (Krishnakumar and Ramesh 2022), S.R.T. campus HNB Garhwal University (Dobhal and Uniyal 2023). Present study aimed to examine the vascular plant diversity in one of most premier and heritage academic institution of the North Bihar, India i.e., Langat Singh College (L.S. College), Muzaffarpur, Bihar, India.

MATERIAL AND METHODS

Study site: Langat Singh College is the premier, highly established and one of oldest heritage college of North Bihar, founded in year 1899. Campus is having habitat for rich biodiversity of several indigenous, exotic plants as well as home to few rare and disappearing plant species.

The main campus geographically located at 26°07′N and 85°24′E. City has humid subtropical climate. The wet season is oppressive and mostly cloudy, the dry season is mostly clear, and it is hot year-round. Temperature of the city varied from 10°C to 40°C, rarely below 10°C and above 45°C. The hot summer season lasts from March *to* July, with an average daily temperature ranges from a high of 40°C to a low of 29°C. Winter season lasts for 2 months and is pleasant cool with daily temperature varied from 06° to 20°C. The summer season have good chances of the rainfall, while the winters have very little. Relative humidity varied up to 90% (max.) to 18% (min.). On an average, there is an approximate 1271 mm/ 50.0 inch of precipitation that occurs over the year. The most probable natural vegetation of north Bihar including Muzaffarpur is tropical mix deciduous type. The deciduous vegetation characterized by woody trees, which remain leafless during summer and have open canopy. Ground flora is seasonal.

Methodology: The present flora is based on the field surveys conducted continuously during the year 2021-2022. Weekly field observations were made for the collection and identification of different species. The flowered twigs were collected for identifying the plant species. Digital photographs of plants were also taken. The Identification of plants was carried out with the help of available Flora of Bihar and other standard publications (Haines 1921-1925, Singh et

al 2001) as well as authenticated by expert. The floristic survey primly concern with natural vegetation analysis of campus.

RESULTS AND DISCUSSION

The vegetation in campus majorly dominated by trees (51%), followed by grasses, climbers, creepers (22%), shrubs (14%) and herbs (13%) (Fig. 1). In woody plants, more dominant families are: *Swietenia macrophylla* and *S. mahogany (*Mahogani*)*, *Ficus benghalensis*, *F. religiosa, Azadirachta indica, Mangifera indica*, *Phoenix dactylifera* (Date Palm), *Cassia abbreviate (*Sjambok pod*), C. fistula* (Golden Shower tree), *Cocos nucifera (*coconut tree*)*. In case of thorny and shrubby plants; *Callistemon viminalis (*wheeping bottle brush*), Albizia julibrissin (*pink silk tree), *Ixora coccinea* (Ixora), *Leucaena leucocephala (*Su babool*)* are prominent. The species of grass and creepers typical to humid subtropical climate observed were *Ureana lobata* (Congo jute), *Cynodon dactylon* (Doob grass), *C. rotundus, Parthenium hysterophorus* (congress grass) *Colocasia esculenta* (Elephent ear), *Ipomoea,* Hydrocotyle*, Phyllanthus amarus* (Gale Of Wind) present is the swampy region of the campus.

Family based analysis of plant vegetation in field survey conducted in campus area shown about 91 species representing 80 genera belonging to 38 families have been identified, excluding the lichens, bryophytes and mycoflora which was not possible during the present study (Fig. 2 and 3). Out of the identified plant species, 43, 18 and 29 species belongs to woody trees, non-woody shrubby and herbaceous species, grasses, creepers, climbers and semi-aquatic plants. In listed plants, 89 belong to the angiosperms which include 83 species of dicotyledons and 6 species of monocotyledons. In Dicots, Meliaceae, Fabaceae, Moraceae are the dominant families present in the campus. The monocotyledons represent 6 families dominated

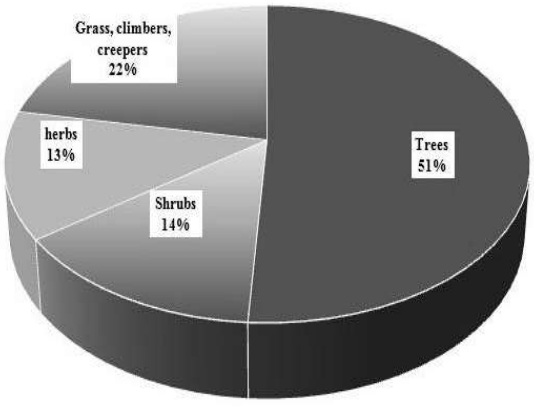

Fig. 1. Analysis of habit wise distribution of plant species in the campus area

Table 1. Plant species recorded in Langat Singh College campus, Muzaffarpur, Bihar

Botanical name	Common name	Family
Achyranthes aspera	Apamarga	Amaranthaceae
Aegle marmelos	Indian Bael	Rutaceae
Albizia julibrissin	Pink silk tree	Fabaceae
Allamanda blancheti	Purple Allamanda	Apocynaceae
Alstonia scholaris	Saptaparni	Apocynaceae
Alternanthera spp.	Joyweed	Amaranthaceae
Amaranthus spinosus	Spiny amaranth	Amaranthaceae
Artocarpus heterophyllus	Jackfruit	Moraceae
Azadirachta indica	*Neem Tree*	Meliaceae
Ageratum conyzoides	*billy goat weed*	Asteraceae
Bauhinia variegata	*kachnar*	Fabaceae
Boerhavia diffusa	*Punarnava*	Nyctaginaceae
Borassus flabellifer	Toddy Palm tree	Arecaceae
Bougainvillea glabra	Bougainvillea (Pink)	Nyctaginaceae
Bryophyllum pinnatum	Pathharchatta	Crassulaceae
Callistemon viminalis	*Weeping Bottle brush*	Myrtaceae
Calotropis gigantea	Aak, Mudar	Apocynaceae
Calotropis procera	Safed Aak, Mudar	Apocynaceae
Cascabela thevetia	Kaner (Yellow flower)	Apocyanaceae
Cassia abbreviata	Sjambok pod	Fabaceae
Cassia fistula	Amaltas (Golden Shower tree)	Caesalpiniaceae
Catalpa bignonioides	Indian bean tree	Bignoniaceae
Catharanthus roseus	pink periwinkle	Apocynaceae
Ceratophyllum demersum	Hornwort	Ceratophyllaceae
Centella asiatica	Gotu Kola	Apiaceae
Chrysopogon lancearius	*Grass family*	Poaceae
Citrus maxima	Batawi-nimbu	Rutaceae
Cocos nucifera	Coconut tree	Arecaceae
Codiaeum variegatum	Croton	Euphorbiaceae
Colocasia esculenta	Elephant's ear	Araceae
Codiaeoum variegatum	Variegated croton	Euphorbiaceae
Curculigo orchioides	Kali musli	Hypoxidaceae
Cycas revoluta	Cycas	Cycadaceae
Cymbopogon gidarba	*Lemongrass*	Poaceae
Cynodon dactylon	Doob or Durva	Poaceae
Cyanthillium cinereum	Sahadevi	Asteraceae
Cyprus rotundus	Java grass	Cyperaceae
Dalbergia sissoo	Sheesham tree	Fabaceae
Delonix regia	Flame tree	Fabaceae
Dryopteris ludoviciana	Southern woodfern	Dropteridaceae
Eclipta alba	False daisy	Asteraceae
Eclipta prostata	False daisy or Bhringaraj	Asteraceae
Eucalyptus globulus	*Eucalyptus*	Myrtaceae
Euphorbia hirta	*Asthma plant*	Euphorbiaceae
Euphorbia prostata	Ground Spurge	Euphorbiaceae
Ficus bengalensis	*Banyan tree*	Moraceae

Cont...

Table 1. Plant species recorded in Langat Singh College campus, Muzaffarpur, Bihar

Botanical name	Common name	Family
Ficus racemosa	*Goolar*	Moraceae.
Ficus religiosa	Peepal tree	Moraceae
Grevillea robusta	*Silk oak*	Proteaceae
Haldina cordifolia	Kadamb	Rubiaceae
Hibiscus rosa-sinensis	Gurhal, China rose	Malvaceae
Hydrocotyle spp.	Indian pennywort	Apiaceae
Ipomoea aquatica	Water Morning Glory	Convolvulaceae
Ipomoea cairica	Railroad creeper	Convolvulaceae
Ixora coccinea	Ixora	Rubiaceae
Lantana camara	Lantana	Verbenaceae
Leucaena leucocephala	Su babool	Myrtaceae
Litchi chinensis	Lychee	Sapindaceae
Mangifera indica	Mango tree	Anacardiaceae
Mikania micrantha	Climbing hempweed	Asteraceae
Malvestrum tricuspidatum	False Mallow	Malvaceae
Miscanthus sinensis	Zebra grass	Poaceae
Moringa oleifera	Drumstick tree	Moringaceae
Morus nigra	Black mulberry	Moraceae
Morus rubra	Red mulberry	Moraceae
Murraya paniculata	Orange jessamine	Rutaceae
Musa paradisiaca	Banana	Musaceae
Nerium odorum	White/ pink kaner	Apocynaceae
Oxalis corniculata	Yellow Wood Sorrel	Oxalidaceae
Parthenium hysterophorus	congress grass	Asteraceae
Persicaria maculosa	lady's thumb	Polygonaceae
Pongamia pinnata	Indian beech	Fabaceae
Phoenix dactylifera	Date Palm (Khajur)	Arecaceae
Phyllanthus amarus	Gale Of Wind	Phyllanthaceae
Phyllanthus emblica	Amla	Phyllanthaceae
Pithecellobium dulce	Jangal Jalebi	Fabaceae
Platycladus orientalis	Chinese thuja (morpankhi plant)	Cupressaceae
Polyalthia longifolia	False Ashoka tree (glossy leaves)	Fabaceae
Prosopis spicata	Shami	Fabaceae
Punica granatum	Pomegranet	Lythraceae
Psidium guajava	Guava	Myrtaceae
Ranunculus scleratus	celery-leaved buttercup	Ranunculaceae
Roystonea regia	Royal Palm	Arecaceae
Saraca asoca	Ashoka plant	Fabaceae
Swietenia macrophylla	Mahogany	Meliaceae
Swietenia mahogani	American mahogany	Meliaceae
Syzygium cumini	Jamun	Myrtaceae
Tectona grandis	Teak	Lamiaceae
Thuja occidentalis	Thuja	Cupressaceae
Ureana lobata	Congo jute	Malvaceae
Vetiveria zizanioides	Khus	Poaceae

including Poaceae, Araceae, Arecaceae, Cyperaceae, Musaceae and Hypoxidaceae In addition one species of Gymnosperm (Cycadaceae) i.e., *Cycas revoluta* and one is Pteridophytic (Dryopteridacae) i.e. *Dryopteris ludoviciana* were also observed (Table 1, Fig. 4). The distribution and

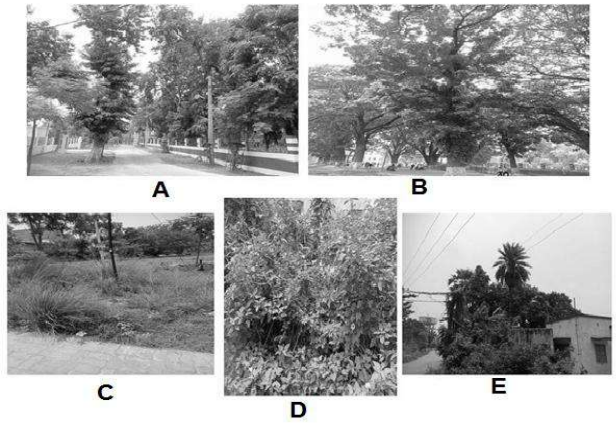

Fig. 2. A & B. Panoramic view of the main campus of L.S. College. C: road side view, D & E Floras behind Art department and nearby Botany department

Fig. 3. Floristic diversity of L.S. College campus

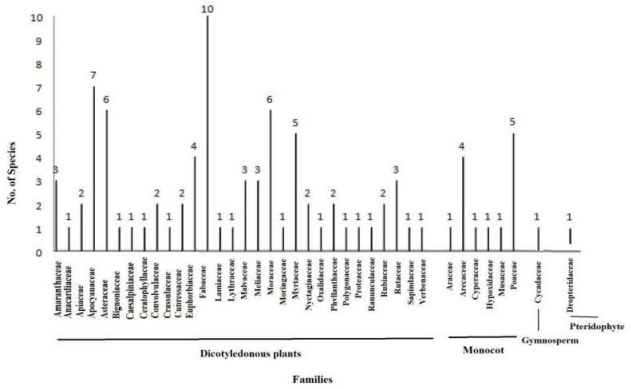

Fig. 4. Comparative analysis of species composition of different families in the campus

occurrence frequency of different plants shows variation along with temporal and seasonal variations (Satapathy and Das 2021, Ashrafuzzaman et al 2023).

CONCLUSION

The study reveals that Langat Singh college campus holds a highly diversified flora and rich in the plants of economic importance. Among the different plant species higher diversity found in dicotyledonous woody species while the lowest diversity found in shrubby species. This study also reveals that the abstract plant community of this college campus is – *Swietenia* and *Cassia abbreviata*. The most dominant dicot family in campus is Fabaceae whereas in monocot Poaceae distributed in dominance. Plants resources of campus are also scrutinized for its future sustainable utilization. The majority of the plants recorded from the campus area are timber plants and many are having medicinal value. Introduction of some nonnative species also recorded. The present study would be helpful to derive conservation policies and make sustainable use of plant resources of campus flora.

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Effect of Root Pruning and Nitrogen Application on Growth Performance of *Celtis australis* L. Seedlings in Garhwal Himalaya, Uttarakhand

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***Abstract*:** The present study was conducted at College of Forestry, Ranichauri –Tehri Garhwal (UK) to assess the effect of root pruning and nitrogen application on the growth performance of *Celtis australis* seedlings. The seedlings roots were pruned at 0 , 6 and 12 cm from the collar region and nitrogen was applied @ 0, 50, 100 and 150 Kg ha^{-1}. The growth performance, physiological and nutrient attributes *viz.* shoot length, root length, collar diameter, number of leaves per plant, dry weight of shoot, root and leaves, survival percent, white root regeneration, chlorophyll content and NPK content and uptake of *Celtis australis* seedlings were significantly enhanced with root pruning and nitrogen application. The root pruned at 12 cm from collar region and application of nitrogen @ 100 Kg ha^{-1} gave the best results for growth of *C. australis* seedlings. Whereas, the seedlings of control treatments of both the factors showed the least values for growth and physiological attributes.

***Keywords*:** Root pruning, Nitrogen application, Growth performance, Physiological, Nutrients attributes

Celtis australis L. is an important multipurpose tree species of Garhwal Himalaya.It is mainly grown for fodder, fuel, timber and plays a very important role in socioeconomic structure in hilly areas. Its leaves are highly palatable, nutritious and tannin-free and are available during the period of scarcity of green fodder (Yadav and Bisht 2013). The wood of *C. australis* is also suitable for carving and making musical instruments, sports equipments and paddles (Brus 2005). It can be grown in any type of soil, well-drained loamy, sandy soil and also on dry gravels soil and is found very drought resistance once established (Komarov 1968). However, poor germination of seeds in nursery was recorded and one year old seedlings have been found suitable for the plantation in field condition (Singh et al 2006).

Roots are one of the most important plant organs which are commonly found under the soil with the positive gravitropism. Compared to the above ground, plant parts such as stems or leaves which get more attention, roots get less attention because their existence is underground or below soil. Roots play an important role in supporting the plant for better growth or for long time survival of plants, providing support to stems and shoots above the ground and also supporting nutrients and water absorption under the ground and serving as nutrient storage in some species (Tjitrosoepomo 2009). A good and well established portion of the root system to shoot system in plants is more important, which can be attained by the root pruning techniques. Root pruning is one of the most familiar and important practice of removing the small portion of roots from the plants root system (Chauhan et al 1994a,b, Gazal et al 2004). Root pruning is a technique to regenerate and nurture tree size including canopies and roots for attaining to maximum production (Marini 2014).

Plants need nutrients to grow and fertilizers are a good source of nutrients. Nitrogen is the most important nutrient element which is essential for the endurance of all livelihoods (Rosolem 2017). Nitrogen (N) has an impact on all aspects of plant function in growth, development and from metabolism to resource allocation (Yousaf et al 2021). Generally fertilizers are used to maintain and influence the nutritional circumstances of different cropping structure. Once nitrogen fertilizers are applied to cropping systems, the fertilizers are directly absorbed by plants root system (Liu et al 2014). Fertilization is also reported to increase leaf nutrient, dry matter, fruit yield and chlorophyll content in plants (Raese et al 2007).

In the hills, transportation of root pruned seedlings in comparison to transportation of containerised grown seedlings from nursery to plantation sites reduces transportation costs and better establishment. The nitrogen application may further be beneficial for the quick establishment of seedlings. Thus, keeping in view above points, present study is carried out to study the performance of one year old *C. australis* seedlings in response to root pruning and nitrogen application.

MATERIAL AND METHODS

Experimental site The experiment was conducted at Forest Nursery, College of Forestry, Ranichauri - Tehri Garhwal, Uttarakhand, India located at an altitude of 1850 masl and lies between 30˚15'' N latitude and 78˚ 30'' E longitude. The average monthly minimum temperature ranged from 0.6˚C to 15.4˚C while, average maximum temperature varies from 12.8˚C to 23.4˚C during the period of investigation. A total 427.8 mm rainfall was received during the period of investigation which was 176.5 mm in the month of July and 27.5 mm in December, 2019. The soil of the experimental field has a pH of 6.08 (Jackson 1967), with 1.55 Kg ha^{-1} soil organic carbon (Walkley and Black 1934), 141.12 Kg ha^{-1} available Nitrogen (Subbianh and Asija 1956), 19.65 Kg ha^{-1} available Phosphorous (Olsen et al 1954) and 112 Kg ha^{-1} available Potassium (Stanford and English 1949).

Plant materials and treatment details: One year old seedlings of *Celtis australis* raised in polybags having uniform shoot length were selected for the experiment. The fields were divided in the experimental plot size of 2 m × 2.4 m. The experiment was laid out in Randomized Block Design (RBD) with three replications having 20 seedlings per plot. The roots were pruned at 0 cm (L_1), 6 cm (L_2) and 12 cm (L_3) length from the collar region and four doses of nitrogen i.e. 0 Kg N ha^{-1} (N_1), 50 Kg N ha^{-1} (N_2), 100 Kg N ha^{-1} (N_3) and 150 Kg N ha^{-1} (N_4) were applied. The nitrogen was applied in the form of CAN (Calcium ammonium nitrate) with 25% of available nitrogen in two split doses, half at the time of planting and another half after fifteen days of planting. The seedlings were transplanted to the experimental plots on the onset of monsoon i.e. in mid July with 50 cm spacing between plants and 48 cm between rows. The plots were properly managed with periodic hand weeding and irrigation as and when required.

Observations recorded: The observations on growth, nutritional content and physiological parameters were recorded at 150 days after planting (DAP), except for chlorophyll content which was recorded at 120 DAP. Growth parameters viz. shoot length (cm), root length (cm), collar diameter (cm), number of leaves per plant and dry weight of shoot, root and leaves (g $plant^{-1}$) were recorded. For dry weight, the plant portions were dried in oven at 104°C for 72 hours (or till sample obtained constant weight). In physiological and nutritional parameters: white root regeneration, survival percentage (%), NPK concentration (%) and uptake (Kg ha^{-1}) and chlorophyll content (mg g^{-1}) were determined. The data was subjected to statistical analysis using randomized block design using OPSTAT software.

Table 1. The effect of root pruning length and nitrogen application on shoot length, root length, number of leaves and collar diameter in *Celtis australis* seedlings

	Shoot length (cm)					Root length (cm)					Number of leaves plant-1					Collar diameter (cm)				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
L1	79.28	83.68	89.64	85.40	84.50	26.84	27.53	31.18	30.54	29.02	63.00	95.00	134.00	85.00	94.25	0.81	0.85	1.21	0.96	0.96
L2	87.23	88.38	95.01	90.77	90.34	28.82	30.21	35.91	35.26	32.55	79.83	162.33	96.66	101.83	110.16	0.95	1.24	1.22	1.37	1.20
L3	86.52	88.23	95.17	92.94	90.72	36.00	35.26	42.40	38.97	38.16	81.83	114.00	142.16	147.66	121.41	1.26	1.37	1.46	1.36	1.36
Mean	84.34	86.76	93.27	89.70		30.55	31.00	36.50	34.92		74.88	123.77	124.27	111.50		1.01	1.15	1.30	1.23	
CD (p=0.05)	L	N	L ×N			L	N	L×N			L	N	L×N			L	N	L×N		
	5.31	6.13	N/S			2.43	2.81	N/S			17.73	20.47	35.46			0.04	0.04	0.08		

RESULTS AND DISCUSSION

Shoot length, root length and number of leaves: Shoot length, root length and number of leaves per plant were significantly ($p<0.05$) influenced by root pruning and nitrogen application. In case of root pruning, the maximum shoot length (90.72 cm), root length (38.16 cm) and number of leaves (121.41) were recorded in 12 cm root pruned seedlings while among nitrogen doses, the maximum length of shoot (93.27 cm), root (36.50 cm) and maximum number of leaves (124.27) were obtained in 100 Kg N ha^{-1}. The interaction effect between length of root pruning and nitrogen doses were found to be statistically non-significant for shoot and root length while significant ($p<0.05$) for number of leaves per plant (Table 1). The increase in root pruning lengths showed increase in shoot length due to increase in number of root branching which might have produced high growth-promoting substance which were transferred to the shoot portion. Increase in root length might be due to the availability of water in the soil which increase new root hairs growth, causing absorption of water and nutrients more effectively and also due to the accumulation of auxin on root tips which helps to increase the length of roots. Higher number of leaves per plant might be due to increase in auxin and also its effect on the process of photosynthesis. The similar findings were noted by Sung-Joon et al (2013). Increase in these parameters due to nitrogen application might be due to the increase in cytokinin production which subsequently improves cell growth resulting in higher shoot length and number of leaves per plant whereas, nitrogen fertilizer affects water use efficiency by influencing root growth and enhances nutrient and water acquisition from the soil which helps to increase the root length. These results were similar with the findings of Yang and Fan (2012) and Nigatu et al (2019).

Collar diameter: The root pruning and nitrogen application also had a significant ($p<0.05$) effect on the collar diameter. Among the root pruning treatments, the maximum (1.36 cm) value for collar diameter was recorded in 12 cm root pruned seedlings. The reason may be that the reserve carbohydrates may have been used for the cambial growth and is also influenced by the photosynthesis process. The similar results are reported by Kerketta et al (2017) and Kowalska and Kasprzyk (2018). Whereas, among the nitrogen doses, the highest (1.30 cm) value for collar diameter was reported in N @100 Kg ha^{-1} which might be due to the increase in cytokinin production, which subsequently affects cell wall elasticity, number of meristematic cells and cell growth and increases the root collar diameter. The similar results were obtained in the experiments of Sun et al (2010) and Andivia et al (2011). The interaction effect was also found to be statistically significant ($p<0.05$) (Table 1).

Dry weight of shoot, root and leaves: The dry weight of shoot, root and leaves increases with increasing root pruning length and nitrogen doses and shows significant ($p<0.05$) results among the treatments. For root pruning length, significantly highest dry weight of shoot, root and leaves were recorded in L_3 (12cm root pruned seedlings) i.e., 8.35 g, 7.64 g and 5.08 g respectively. For nitrogen application, significantly highest dry weight of shoot, root and leaves was observed in N_3 (100 Kg ha^{-1}) i.e., 8.39 g, 7.38 g and 5.08 g respectively. Interaction effect of both root pruning and nitrogen doses was also found to be statistically significant ($p<0.05$) (Table 2). This might be due to the increase in auxin production in root pruned seedlings (Miller and Graves 2019) which increases growth parameters (shoot length, root length, collar diameter and number of leaves per plant). The increase in carbohydrates production, proteins synthesis and other organic compounds might have increased the growth of plants which may be responsible for increase in shoot, root and leaves biomass of seedlings. These results are supported by the findings of Luna et al (2014) and Zhang et al (2017).

White root regeneration: The white root regeneration has been significantly ($p<0.05$) affected by both root pruning and nitrogen application. With increase in nitrogen level, root regeneration enhanced and was found maximum in N_3 (22.55). In case of root pruning white root regeneration also increased with increase in length of root pruning and was

Table 2. The effect of root pruning length and nitrogen application on dry weight of shoot, root and leaves in *Celtis australis* seedlings

	Dry weight of shoot (g)					Dry weight of shoot (g)					Dry weight of leaves (g)				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
L1	6.82	7.06	8.29	6.96	7.28	5.78	6.82	6.20	6.56	6.34	3.36	3.07	4.79	5.80	4.25
L2	7.09	7.06	8.50	6.89	7.39	7.26	7.26	7.00	7.86	7.34	4.79	4.82	5.50	3.37	4.62
L3	7.39	8.40	8.39	9.20	8.35	6.10	7.86	8.95	7.64	7.64	4.51	5.51	4.84	5.45	5.08
Mean	7.10	7.51	8.39	7.68		6.38	7.31	7.38	7.35		4.22	4.47	5.04	4.87	
CD (p=0.05)	L	N	L×N			L	N	L×N			L	N	L×N		
	0.52	0.60	1.05			0.48	0.55	0.96			0.44	0.51	0.88		

found maximum (25.91) in L_3 (root pruned at 12 cm from collar region). The interaction effect was also found to be statistically significant ($p<0.05$) (Table 3). The supply of fertilizers might have contributed to influence the root stimulation of seedlings and the process of root initiation in plants. The increase in auxin and cytokinin concentration in root xylem sap after 24 hours of root pruning has been reported by Carlson and Larson (1977), which might have increased the root regeneration in seedlings. This is in line with the findings of Nambiar et al (1979) in *Pinus radiata* and douglas fir. The age and physiological status of the plant also have an influence on white root regeneration, the younger the plant the higher the root regeneration potential (Geisler and Ferree 1984). The similar finding was observed by Vasishth et al (2007).

Survival percent (%): Root pruning and nitrogen application also revealed significant ($p<0.05$) effect on the survival percent of *C. australis* seedlings. The survival percent was improved with the application of nitrogen and the highest percent (94.66%) was observed with 100kg N/ha (N_3) and root pruned seedlings at 12cm from collar region (L_3) treatment recorded the maximum (94.50%) survival percent among the root pruning treatments. The interaction of both factors, also revealed significant ($p<0.05$) variations among the various treatments (Table 3). Addition of nitrogen fertilizer increased the seedling length; the larger seedlings generally display a greater photosynthetic rate and have a higher net carbon gain which may increase the survival rate. The root growth and fibrous root development improves the root surface area and root-soil contact required for adequate water and nutrient absorption for plant growth thus, avoiding planting stress for ensuring plant survival. Similar observations were made by Grossnickle (2005) and Luis et al (2009).

Chlorophyll 'a', 'b' and total chlorophyll (mg g^{-1}): The perusal of data for chlorophyll 'a', 'b' and total chlorophyll revealed significant ($p<0.05$) effect of root pruning and nitrogen level. The data revealed that the root pruning length of 12 cm (L_3) had significant effect on Chlorophyll 'a' 'b' and total chlorophyll, whereas the maximum concentration was recorded in L_3 i.e., 2.48 mg g^{-1}, 13.84mg g^{-1} and 12.19mg g^{-1} respectively. This might be due to residual effects which produced the highest significant content of chlorophyll (Yehia et al 2014) and also due to the higher sucrose content present in the seedlings (Tognetti et al 2013). Among the nitrogen doses, maximum concentration of chlorophyll 'a', 'b' and total chlorophyll, was obtained under N_3 i.e., 3.41mg g^{-1}, 12.62 mg g^{-1} and 11.11mg g^{-1} respectively, which might be due to the addition of nitrogen which promotes the formation of active photosynthetic pigments by increasing the amount of

Table 3. The effect of root pruning length and nitrogen application on white root regeneration, survival percent and chlorophyll content in *Celtis australis* seedlings

	White root regeneration				Survival percent (%)					Chlorophyll 'a' (mg g^{-1})					Chlorophyll 'b' (mg g^{-1})					Total Chlorophyll (mg g^{-1})				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
L1	12.66	12.33	16.33	16.50	14.45	80.00	75.00	98.00	86.00	84.75	0.84	0.48	1.99	2.85	1.54	9.39	9.56	9.44	11.18	9.89	9.21	8.75	6.64	9.31	8.47
L2	16.50	16.50	16.66	16.33	16.50	90.00	94.00	88.00	94.00	91.50	2.07	2.82	1.58	1.21	1.92	10.17	9.98	7.50	10.58	9.55	8.30	8.40	8.28	9.91	8.72
L3	16.16	26.00	34.66	26.83	25.91	90.00	94.00	98.00	96.00	94.50	0.46	1.63	6.68	1.17	2.48	10.92	11.74	20.92	11.78	13.84	9.63	10.36	18.43	10.36	12.19
Mean	15.11	18.27	22.55	19.88		86.66	87.66	94.66	92.00		1.12	1.64	3.41	1.74		10.16	10.42	12.62	11.18		9.04	9.17	11.11	9.86	
CD (0.05)	L	N	L×N			L	N	L×N			L	N	L×N			L	N	L×N			L	N	L×N		
	2.289	2.643	4.579			1.70	1.96	3.40			0.30	0.34	0.60			1.47	1.70	2.95			0.88	1.02	1.77		

Table 4. The effect of root pruning length and nitrogen application on NPK concentration in *Celtis australis* seedlings

	Nitrogen concentration (%)					Phosphorous concentration (%)					Potassium concentration (%)				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
L1	0.30	0.01	0.28	0.01	0.15	0.22	0.28	0.24	0.32	0.26	0.25	0.50	1.25	0.50	0.62
L2	0.01	0.48	0.31	0.30	0.27	0.28	0.28	0.32	0.26	0.28	0.50	0.24	1.50	0.50	0.68
L3	0.87	0.78	1.04	1.29	0.99	0.23	0.26	0.39	0.30	0.29	1.00	1.25	1.25	1.50	1.25
Mean	0.39	0.42	0.54	0.53		0.24	0.27	0.31	0.29		0.58	0.66	1.33	0.83	
CD (p=0.05)	L	N	L×N			L	N	L×N			L	N	L×N		
	0.01	0.02	0.03			0.01	0.02	0.03			0.23	0.26	0.46		

Table 5. The effect of root pruning length and nitrogen application on NPK uptake in *Celtis australis* seedlings

	Nitrogen uptake (kg ha^{-1})					Phosphorous uptake (kg ha^{-1})					Potassium uptake (kg ha^{-1})				
	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean	N1	N2	N3	N4	Mean
$^{L}1$	0.71	16.43	0.18	17.56	8.72	12.65	7.82	14.37	15.66	12.62	27.68	12.88	34.52	27.81	25.72
$^{L}2$	26.40	0.70	16.95	7.13	12.79	15.00	16.31	4.28	15.00	12.64	13.23	26.97	78.40	6.77	31.34
$^{L}3$	14.09	42.60	101.21	64.44	55.58	4.15	18.59	30.60	12.73	16.51	18.06	61.20	77.45	116.35	68.26
Mean	13.73	19.91	39.44	29.71		10.60	14.24	16.41	14.46		19.65	33.68	63.45	50.31	
CD (0.05)	L	N	L×N			L	N	L×N			L	N	L×N		
	0.01	0.01	0.02			1.75	2.02	3.50			0.37	0.43	0.75		

stromal and thylakoid proteins in leaves (Filho et al 2011). Chlorophyll and carotenoid synthesis are also dependent upon mineral nutrition (Daughtry and Mcmurtey 2000). The interaction effect for chlorophyll 'a', 'b' and total chlorophyll between length of root pruning and nitrogen doses was found to be statistically significant ($p<0.05$) (Table 3).

Nutrients content (%) and uptake (Kg/ha): Root pruning and nitrogen application had significant ($p<0.05$) effect on NPK content and uptake. Among L_3 root pruning length, the maximum NPK content of 0.99%, 0.29% and 1.25% were recorded and similarly the highest NPK uptake of 55.58 Kg ha^{-1}, 16.51 Kg ha^{-1} and 68.26 Kg ha^{-1} were obtained. This might be due to the absorption capacity of roots, mass flow and diffusions of roots. As the root system regenerates, uptake may increase accordingly. The efficiency of roots in uptake of nutrients depends on the amount of surface in contact with soil and on the permeability of root surface. Root regeneration after root pruning provides more root branches which increases the absorbing surface. These factors suggest that uptake of nutrients will be the same or even improved when the root system is regenerated. The decrease in concentration and uptake of nutrients (NPK) in severely pruned seedling (6 cm) may be due to greater decrease in root biomass which has affected the absorption capacity of root, which could have decreased xylem functioning, poor conductivity of the soil surrounding the roots, increase in the content resistance between soil and roots (Dhiman 1991). The similar findings were reported by Vasishth et al (2007) in *Acacia catechu*. Among the nitrogen application, the maximum concentration and uptake of NPK were recorded in N_3 i.e., 0.54%, 39.44 Kg ha^{-1}, 0.31%, 16.41 Kg ha^{-1} and 1.33%, 63.45 Kg ha^{-1}. With increasing nitrogen application, nitrogen content and uptake has increased in the seedlings up to N3 level (100kg N/ha) and decreased afterwards. Nitrogen content in plants increased due to the good availability of applied fertilizer for the whole growing period (Kaplan et al 2015). Increase in concentration of highly mobile elements such as P and K in stressed plants could be partly due to their absorption throughout the seasons (Mead 1984). The similar findings were also reported by Fang et al (2017) and Mensah et al (2020). The interaction effect for NPK uptake between length of root pruning and nitrogen doses was also found to be statistically significant at 150 days after planting ($p<0.05$) (Table 4 & 5).

CONCLUSIONS

On the basis of results of the present study, it can be concluded that root pruning and nitrogen application enhanced the growth performance and physiological characteristics of *Celtis australis* seedlings. Root pruned at 12 cm from collar region and application of nitrogen @ 100 Kg ha^{-1} were considered best for the growth performance and establishment of the seedlings**.** Nitrogen application and root pruning combinations recovered the plants from the stress condition and enhanced the morphological as well as physiological characteristics of seedlings.

AUTHOR CONTRIBUTIONS

Conceptualization, P.U. and A.V.; methodology, A.V., B.S., D.R. and I.S.; software, P.U., D.R. and S.T.; investigation, P.U.; writing-original draft preparation, P.U. and S.T.; writing-review and editing, P.U., A.V., B.S., D.R. and I.S.; supervision, A.V., B.S., D.R. and I.S. .

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Influence of Plant Growth Regulators, Urea and Micronutrient on Growth, Yield and Quality of Rangpur Lime (*Citrus limonia* Osbeck)

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***Abstract*:** The present study was conducted at Central Agricultural University. Pasighat, on influence of the pre-harvest application of NAA and GA_3 combined with 1% urea and 0.5% $ZnSO_4$ on vegetative growth, fruit drop, yield and fruit quality of *Citrus limonia* Osbeck, during 2020-2021. The experiment consisted of ten treatments with NAA, GA_3, $ZnSO_4$ and Urea. The trees sprayed with NAA @ 30 ppm + GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% urea recorded the maximum plant height, minimum days for flowering, fruit drop percentage, acidity, higher ascorbic acid, total, reducing and non-reducing sugars and fruit juice content. The treatment combination of NAA @ 10 ppm + GA_3 @ 10 ppm + 0.5% $ZnSO_4$ + 1% urea performed better with respect to stem girth (38.98 cm). The current study revealed that NAA @ 30 ppm + GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% urea is the best treatment for enhancing plant growth, reproductive and biochemical parameters of fruit.

***Keywords*:** PGRs, Urea, $ZnSO_4$, Fruit quality, Rangpur lime

Citrus is a globally important commercial fruit crop. It is India's third most important fruit crop, behind mango and banana. Citrus fruits are regarded as an excellent diet and the most popular fruit in the country. With consideration to generating quality planting material many rootstocks used for different citrus species out of which 'Rangpur lime' is also one of the widely used rootstock in India. It is a salt and drought tolerant, cold hardy and resistant to tristeza, xyloprosis and exocortis. It is also commonly used rootstock, notably in Brazil, due to its tolerance to the tristeza virus and its adaptation to water deficiency. With scion variations, Rangpur lime also has excellent agronomic qualities that enable high production and good fruit quality (Silva et al 2019). Among the citrus fruits grown in India, Rangpur lime is not only a crucial rootstock for Nagpur mandarin, sweet range, Coorg mandarin and pummelo, but also a popular rootstock for "Khasi Mandarin," which is grown from seeds. Because of its tolerance to salt and drought, early fruit set, lengthy fruit retention on the tree, and resistance to the tristeza virus, the cultivar is used as a rootstock in many other states (Dilip et al 2017).

Among PGRs, auxins have a direct effect on abscission by promoting a delay in abscission, resulting in an increase in fruit yield and quality. For the decrease of fruit physiological drop, 2-4 dichlorophenoxy acetic acid, NAA and Gibberellic acid have been tried (Fahad et al 2014). The use of PGRs can re-enforce hormone balance or delay precocious fall and losses prior to harvest. Auxins inhibit fruit drop by keeping cells at the abscission zone and preventing the formation of hydrolytic enzymes such as cellulase and polygalacturonase, which destroy the cell wall. The activity of auxin in strengthening the cells in the abscission zone (Basu et al 2013), which is located at the peduncle, may be the cause of the decreased fruit drop percentage. The use of gibberellic acid to prevent fruit drop at various phases throughout fruit growth and development has become a widely used practice in the citrus (Hikal et al 2013). The major application of plant growth regulators enhances internal fruit quality, influence flowering, fruit set and fruit drop as well as to influence fruit quality traits in different citrus species (Harsimrat et al 2015). Exogenous applications of these growth regulators have been tested on a variety of citrus species either alone or in combination either at full bloom or at the preharvest stage(Nawaz et al 2008). Bhatt et al (2016) observed that on *Citrus limon* the least fruit cracking was found under NAA @ 50 ppm, the lowest fruit drop was under GA_3 (20 ppm), the maximum fruit number and seed weight was under GA_3 (10 ppm). Choudhary et al (2013) in Nagpur mandarin observed that the application of GA_3 increased the number of vegetative shoots, which significantly increase plant spread and crown volume. Considering this in point, the present experiment was undertaken to study the effect of pre-harvest spray of PGRs, urea and micronutrient on reducing fruit drop, increasing yield and quality of lime cv. Rangpur lime.

MATERIAL AND METHODS

The present investigation was carried out in the year 2020 at Central Agricultural University, Pasighat, Arunachal

Pradesh, India. Nine years old lime trees cv. Rangpur Lime planted at a spacing of 6 m × 6 m was used as experimental materials. The experiment was laid out in RBD consisting of ten treatments and four replications. The treatments applied were: T_1 (Control), T_2 (NAA @ 10 ppm + 0.5% $ZnSO_4$ + 1% urea), T_3 (GA_3 @ 10 ppm + 0.5% $ZnSO_4$ + 1% Urea), T_4 (NAA @ 20 ppm + 0.5% $ZnSO_4$ + 1% urea), T_5 (GA_3 @ 20 ppm + 0.5% $ZnSO_4$ + 1% Urea), T_6 (NAA @ 30 ppm + 0.5% $ZnSO_4$ + 1% urea), T_7 (GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% Urea), T_8 (NAA @ 10 ppm + GA_3 @ 10 ppm + 0.5% $ZnSO_4$ + 1% urea), T_9 (NAA @ 20 ppm + GA_3 @ 20 ppm + 0.5% $ZnSO_4$ + 1% urea) and T_{10} (NAA @ 30 ppm + GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% urea). Regular manures, fertilizer application, and plant protection measures were undertaken in the field. Two PGRs *viz*., NAA and GA_3 @ 10, 20 and 30 ppm were applied as a foliar spray to the plants along with 1% urea and 0.5% $ZnSO_4$. The water-insoluble PGRs were initially dissolved in a small quantity of ethanol. All spray solutions were prepared separately and made up the volume of the required quantity with tap water. PGRs *viz*., NAA and GA_3 were applied on the same day but separate foliar spray and 0.5% $ZnSO_4$ and 1% Urea were applied 10 days prior to their application with a knap-sack sprayer without any adhesive chemical to the foliar spray. First foliar spray of NAA and GA_3 @ 10, 20 and 30 ppm and $ZnSO_4$ (0.5%) along with urea (1%) was applied during April, June and October. The fruits were harvested when they are fully matured and start to develop attractive color. Plant growth and reproductive observations like plant height (cm), stem girth (cm), tree canopy (m), days to flowering (50% flowering), and fruit quality attributes like TSS (%), titratable acidity (%), total sugar (%), reducing sugar (%) and vitamin C (mg/100 g) were estimated as per standard procedures of AOAC (2002) using five fruits randomly selected from each treatment. The data on the mean values of all characters were statistically evaluated using the OPSTAT programme.

RESULTS AND DISCUSSION

Tree growth: The various treatment combinations had a substantial impact on plant height (Table 1). The treatment T_{10} had the highest increase in plant height (346.25 cm) being followed by T_7 (322.50cm), T_8 (318.00cm) and T_5 (310.50cm) while the control (T_1) had the lowest rise in plant height (269.00 cm). The gibberellins (GA_3), function as a growth promoter and accelerate the cell elongation in part by activating the intercalary meristematic area of developing shoots, also lengthen internodal distances between branches as reported by Awati M and Kiran K C (2018) in acid lime. Prasad et al (2015) mentioned that plant growth regulator (2,4-D) treated in conjunction with urea in 'Kinnow Mandarin', were more successful in promoting vegetative development than PGRs applied alone. Urea's ability to stimulate plant growth may be ascribed to nitrogen, a crucial elemental component of chlorophyll, the substance that allows plants to absorb solar energy and use it to convert atmospheric carbon dioxide into carbohydrates through photosynthesis. Energy for plant development and growth is provided by the carbohydrates so synthesized. The growth of plants is increased when urea is applied to foliar. Kacha et al (2012) also mentioned that 200 ppm of NAA spray, resulted in the greatest height (177.3cm) of the phalsa bush.The maximum tree canopy N-S (4.67m) and E-W (4.43m) was in trees sprayed with NAA @ 30 ppm + GA_3 @ 30 ppm + 1% urea + 0.5% $ZnSO_4$, whereas minimum spread was in T_4 from N-S

Table 1. Effect of pre-harvest spray of PGRs, urea and micronutrient on plant growth parameters and flowering period of rangpur lime

Treatments	Plant height (cm)	Stem girth (cm)	Tree canopy (m)		Flowering period (Days)
			N-S	E-W	
T_1	269.00	30.78	3.97	3.62	14.38
T_2	299.50	34.23	4.25	3.97	15.25
T_3	293.50	33.28	4.27	3.65	13.81
T_4	287.25	38.25	3.83	3.95	14.63
T_5	310.50	35.65	4.28	4.17	13.00
T_6	289.25	35.78	4.22	4.11	14.50
T_7	322.50	34.38	4.29	3.93	13.00
T_8	318.00	37.13	3.98	4.06	13.50
T_9	253.25	38.03	4.39	3.96	12.50
T_{10}	346.25	38.98	4.67	4.43	11.63
C.D @ 1%	29.82	4.53	0.30	0.29	0.87

(3.83 m) direction and in control trees from E-W (3.62 m) direction (Table 1). This expansion of the tree canopy may be caused by the efficient conversion of food components that have been stored for the beginning of more side branches in the trees. After spraying GA_3, the growth metrics such as plant height, mean spread, and canopy volume increased greater in all treatments (apart from control). It has been primarily attributed to the effect of GA_3, which encourages cell elongation, increases cell size and also stimulates cell multiplication. The findings of the current study agreed with those of Baskaran et al (2009) in acid lime. The treatments had a significant influence on the stem girth of the tree. Treatment T_{10} (38.98 cm) greatly increased the stem girth than control (30.78 cm), however treatments T_9, T_8 and T_4 were at par with T_{10}.The number of days to reach flowering was significantly affected by the quantity of growth regulators and chemicals used (Table 1). These chemicals are also used to control tree production by either limiting vegetative development or promoting blooming. The minimum flowering period was observed in T_{10} (11.63 days) and maximum was recorded in T_2(15.25 days). Applying GA_3 and $ZnSO_4$ resulted in a rise in the number of fruits per tree, which may have been caused by the treatment's initial tendency to increased flowering. The GA_3 treatment's effect on the promotion and diversion of metabolites and flower-inducing compounds may be the cause of the lateness in flowering in the control group by changing the destiny of reproductive buds to vegetative buds and inhibiting flower development. The cultivar, genetic make-up, habitat, and cultural traditions are only a few of the variables that influence the occurrence of blooming in plants (Harsimrat et al 2015).

Influence on yield and yield attributing traits: There was a significant relationship between the various treatments and yield attributing traits (Table 2). Due to higher blossoming in March, there were significantly more fruits/trees. Treatment T_{10} was determined to be the most effective, producing 814.25 fruits per tree, subsequently followed by T_9 (767.50), whereas control trees had the fewest fruits (437.25). T_{10} had the largest fruit output per tree due to its increased blooming inclination (129.71 Kg). The pool data for this feature showed the greatest value in treatment T_{10} (129.71 kg), which is at par with the results of treatment T_9 (120.85 kg), and the lowest yield was recorded in control trees (72.53 kg). The lowest fruit drop percentage were observed in treatment T_{10} (33.47%), which is equivalent to T_8, T_7 and T_9 and the highest was noticed in the control trees (56.48%).GA_3 enhanced the number of fruits per tree and the total yield both independently and in combination with auxin. Citrus fruit quality and yield are improved by auxins, among PGRs that directly affects abscission by delaying it (Harsimrat et al 2015). Multiple abscission zones arise within the same inflorescence because the abscission of fruits is typically accompanied by structural changes (Bermejo et al 2018). Because the cells become free in the abscission zone and fruits abscised. The corresponding enzymes breakdown pectin, hemicelluloses, and cellulose as mechanical tension separates and softens the cell wall (Zhang et al 2022). In plants, NAA significantly boost the production of cellulose fibre and spraying NAA in various fruit crops at varying concentrations prevents fruit drop in the majority of fruit trees. Plant growth regulators have a significant impact on early reproductive processes in citrus, showing that hormones play a crucial role in the regulatory systems that regulate fruit set and the abscission of ovaries and fruitlets. Ghosh et al (2012) observed that the NAA applied at 15ppm was the most efficient in reducing fruit drops at various months after fruit

Table 2. Effect of pre-harvest spray of PGRs, urea and micronutrient on fruit drop, yield and physical parameters of rangpur lime

Treatments	Fruit drop (%)	No. of fruits/tree	Yield (Kg/tree)	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	No. of seeds/fruit
T_1	56.48	437.25	72.53	5.43	5.40	119.50	17.68
T_2	47.25	473.75	80.53	5.45	5.93	122.85	16.45
T_3	43.26	511.00	75.98	5.70	5.98	124.53	15.50
T_4	41.23	529.50	87.63	6.13	6.29	126.23	13.75
T_5	40.26	630.25	88.96	6.38	5.99	135.00	11.50
T_6	35.69	680.75	103.24	6.27	6.05	147.92	12.00
T_7	35.10	735.75	113.04	6.50	6.12	153.58	11.00
T_8	34.70	728.75	115.34	6.72	6.31	158.25	12.13
T_9	35.15	767.50	120.85	7.20	6.67	166.25	8.75
T_{10}	33.47	814.25	129.71	7.48	7.08	171.38	10.75
C.D. @ 1%	4.39	59.54	11.874	0.48	0.77	6.28	1.82

set, resulting in a twofold increase in fruit output over the control and better fruit size in sweet orange. Kachave and Bhosle (2009) observed that in Kagzi lime concluded that the most effective treatment to enhance total soluble solids, acidity, ascorbic acid and reducing sugar of fruit is NAA 200 ppm + micronutrients mixture @ 1% spray. When combined with zinc, NAA enhanced the yield per tree more than the control. Due to its role in auxin synthesis, zinc may have contributed to the greater increase in fruit production.

Fruit physio-biochemical attributes: The influence of different treatments on fruit length was significant with maximum increase in treatment T_{10} (7.48 cm) followed by T_9 (7.20 cm) and minimum was in T_1 (5.43 cm) (Table 2). Similarly, the treatments had a substantial impact on fruit width. Among all the treatment studied, T_{10} showed highest fruit width (7.08 cm) whereas T_1 depicted the least (5.40 cm). As a consequence of a strong impact on fruit length and width from PGR's, urea and micronutrient foliar spray, the maximum fresh weight of the fruit was in T_{10} (171.38 g) followed by T_9 and the minimum was in T_1 (119.50 g). The increase in fruit weight might be the result of zinc spray which is related to tryptophan, a critical amino acid for fruit growth and development. The contribution of auxin to fruit growth, is based on a higher cell expansion, may account for the improvement in the fruit's overall physical characteristics (fruit length, width, and weight). The increased cell vacuolization that results in larger vesicles, locules, and ultimate fruits is most likely the cause of this enlargement. Hesami and Abdi (2010) observed that NAA @ 100 ppm enhanced bunch weight and improved physical attributes (fruit weight, height, diameter, and size) in date palm. Treatment (T_9) with NAA @ 20 ppm + GA_3 @ 20 ppm + 0.5% $ZnSO_4$ + 1 % urea had few average numbers (8.75) of seeds per fruit . The control group had the most seeds per fruit (17.68 seeds), nevertheless spraying GA_3 can possibly lower the number of seeds in citrus cultivars that produce them, however, this depends on the cultivar (Hung et al 2023). Ullah et al (2012), also indicated that a 200 mg/L GA_3 spray treatment one month after anthesis decreased the number of seeds in Kinnow mandarin.

The treatments significantly increased TSS, acidity, total sugar, reducing sugar, and ascorbic acid (Table 3). The total soluble solid content was highest in T_{10} (8.55 °Brix) while the control depicted the least (7.30 °Brix). The combination of PGR's and micronutrient may respond to the more accumulation of total soluble solids by enriching the nutrient content in the juice sacs. Significantly, the lowest acidity percentage (0.60 %) was with NAA @ 30 ppm + GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% urea, whereas the highest levels (1.30 %) was in control. The acidity of acid lime is mainly due to the presence of citric acid, which is one of the most widely distributed acids in fruits. Sawale et al (2021) concluded that foliar applications of urea, zinc sulphate, and borax in various amounts had an immense effect on reducing acidity. Singh et al (2018) findings in sweet orange cv. Mosambi are also in support of our study. There was substantial difference in vitamin C content between the fruit that had been treated with NAA and GA_3 and untreated. The greatest concentration of vitamin C was in t T_{10} (38.52 mg/100g). The control had the lowest vitamin C content (20.87 mg/100 ml). Fruits with increased vitamin C concentration are more nutrient-dense. The fruits that weren't treated, however, showed a more pronounced decline. Enzymatic loss of L-ascorbic acid, which is transformed into 2-3-dioxy-L-gluconic acid, may be the cause of a drop in ascorbic acid in non-treated fruits (Dosedel et al 2021). Treatment T_{10} recorded the highest total

Table 3. Effect of pre-harvest spray of PGRs, urea and micronutrient on biochemical parameters of lime cv. Rangpur lime

Treatments	TSS (°Brix)	Acidity (%)	Vitamin C (mg/100g)	Total sugars (%)	Reducing sugars (%)	Non-reducing (%)	Fruit juice (ml)
T_1	7.30	1.30	20.87	2.41	0.28	1.92	78.50
T_2	7.98	0.75	22.16	2.62	0.36	2.04	86.00
T_3	7.95	0.62	23.22	2.82	0.33	2.24	85.13
T_4	7.55	0.71	24.64	3.07	0.38	2.42	90.50
T_5	7.55	0.72	25.98	2.89	0.49	2.12	89.23
T_6	8.33	0.62	27.42	2.72	0.58	1.93	88.75
T_7	7.40	0.66	26.57	3.06	0.55	2.26	89.5
T_8	8.15	0.72	29.67	3.22	0.64	2.33	92.50
T_9	8.30	0.61	30.33	3.16	0.66	2.25	94.25
T_{10}	8.55	0.60	38.52	3.86	1.11	2.48	113.25
C.D @ 1%	0.59	0.223	9.44	0.76	0.37	NS*	11.36

sugar content (3.86 %). Same treatment combination also showed the significant variation with greatest levels of reducing sugar (1.11 %) whereas with non-significant differences in non-reducing sugar (2.48 %). On 'Kinnow mandarin', foliar applications of Zn up to 0.6% enhanced tree growth, productivity, and mineral nutrients with greater fruit quality compared to control was also reported by Razzaq et al (2013). Zinc has been shown to play a specific role in the hydrolysis of complex polysaccharides into simple sugars, the synthesis of metabolites, and the quick translocation of minerals and photosynthetic products from other parts of the plant to developing fruits, which increases the weight, volume and size of the fruit (Parmar et al 2014). The treated fruits had considerably more fruit juice than untreated fruits (Table 3). Eventually, juice content recovered was higher in T_{10} (113.25 ml) treated with NAA, GA_3 @ 30 ppm than in control (78.50 ml), which might be due to enhancement of cell division and cell elongation, likely as a result of the GA_3 treated fruits retained firmness and the characteristics of the non-treated fruit as overripe fruit. The increased proportion of juice may also be explained by the fact that hormones control how metabolites are mobilized within a plant, and is well known that growing fruits are particularly active metabolic "sinks" that mobilize metabolites and guide their movement from vegetative structure (Rokayaet al 2016).

AUTHORS CONTRIBUTION

S. Bhanu Varsha – conception, data collection, analysis and interpretation of results, manuscript preparation, P.K. Nimbolkar – conception, design and manuscript preparation, L. Wangchu – Conception and design , Siddhartha Singh - data analysis and interpretation of results

CONCLUSIONS

Rangpur lime' requires constant nutrient management for balancing the vegetative growth reproductive growth as well for quality fruit production. Citrus growers are encouraged to apply the foliar application of NAA @ 30 ppm + GA_3 @ 30 ppm + 0.5% $ZnSO_4$ + 1% Urea, as it appears to be a promising treatment that improved the growth morphology, yield attributing traits and fruit quality. The foliar application of NAA @ 20 ppm + GA_3 @ 20 ppm + 0.5% $ZnSO_4$ + 1% Urea would be recommended with less number of seeds in processing industries of rangpur lime for beverage preparations.

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Productivity Improvement of Pond-Based Production System through Integration of Horti-Livestock-cum-Pisciculture

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***Abstract*:** The present study on pond-based production system model was undertaken at ICAR-National Research Centre on Litchi, Muzaffarpur, Bihar during 2018-2020. The cropping system on pond bunds includes three tier model of litchi cum banana/papaya and seasonal crop based system along with vermi-compost, livestock and makhana with fish culture in pond comprised with 4 models *viz*., Integration of different components like fruit, seasonal vegetables, fish and dairy under model-1(Fish+litchi+banana+vegetables +dairy+vermi-compost) was economical than other models in terms of net return with highest net income of Rs 1,19,400 followed by model-2 (Fish+duck+litchi+papaya+vegetables) which recorded net income of Rs 66,175, and lowest in model-4 (Two row of litchi + papaya in between two litchi plants + field crops and makhana with fishery) of Rs 48,225. The higher benefit: cost ratio (1.58) was obtained with model-2 followed by model-1 (1.46). The system economic efficiency in terms of net return as Rs/day and sustainable value index was also markedly higher with model-1 (Rs. 327/day and 0.73). The highest total system employment generation was also observed in model-1 (385 man-days/year) followed by model-2 and model- 4.

***Keywords*:** Horticulture, Livestock, Pisciculture, Integrated farming system, Eastern India

Land being a non-renewable resource is an essential component to all primary production systems. In India, the excessive demand of land for both agricultural and non-agricultural purposes has resulted in the development of huge stretches of different kinds of wastelands (Patel et al 2020a). Majority of the farmers in India are small and marginal. They often follow a monoculture approach which leads to low farm income. Presently, most of the farmers are concentrating mainly on crop production, which is subjected to a high degree of risk and uncertainty in income due to crop failure by various factors. In this context, integrated farming system (IFS) ensures the highest standard of food production with minimum environmental impact even under highly vulnerable climatic condition (Kumar et al 2015). This integration of components of ecosystem results in sustainable production (Ansari et al 2014). Integration of crop and livestock component has been highly productive, profitable, and environmentally sustainable (Gill et al 2010, Yadav et al 2013). It is a reliable means of obtaining higher productivity with substantial nutrient economy in combination with maximum compatibility and replenishment of organic matters by way of effective recycling of organic residues/wastes (Solaniappan et al 2007). Many attempts have been made to integrate the desirable features of farming system research into mainstream agriculture to develop more relevant, realistic client-oriented and location-specific technologies. Sustainable development through horticulture with livestock and fish based production system has been emerged as a viable way of improving farmers income (Patel et al 2020a). The substantial area of Bihar state is under waterlogged and marshy condition. Majority of the area falls under those districts which are suitable for the litchi cultivation but, the waterlogged area having drainage problems are not fit for production of litchi (Patel et al 2021). Some parts of Bihar remain waterlogged (> 1m surface water logging) for 4-5 months and become unproductive during *Kharif* and very low utilization in *Rabi* season also. Efficient rainwater harvesting and recycling provided new livelihood options for the resource poor farmers by increase in productivity and diversified the agricultural production by growing of remunerative agricultural and horticultural crops integrated with composite pisciculture (Das et al 2014). The low lying waterlogged area of the centre has been converted in to ponds. Plantation of fruit crops along with seasonal crops and integration of livestock on pond dyke while fisheries in pond through integrated approach of farming system has been developed. Keeping the view, a multi-enterprise horticulture, livestock and pisciculture based

integrated farming with pond based production system has been implemented in representative deep low lying areas (1.5-2.5 m water depth) for comparative evaluation of different pond based production system models.

MATERIAL AND METHODS

The present study on pond based production system model was undertaken research farm of ICAR-National Research Centre on Litchi, Muzaffarpur, Bihar during 2018-2020. The experiment site was located at about 26°5'87" N latitude, 85°26'64" E longitude at 210 m asl. The four models of integrated farming system comprised with fruit crops, seasonal crops, makhana, livestock, duckery, and fishery were imposed on ponds and their bunds in different combination including recycling of crop residue for vermi-compost production. The size of the experimental low lying area was 0.80 ha (ponds with dyke) and rain water was accumulated in the ponds during rainy season from the catchment area of about 5 ha. The cultivation of seasonal crops like maize, mustard, faba bean and vegetables like cow pea, cabbage, cauliflower, knol-khol, broccoli and pea were done as intercropping with litchi+banana and litchi+papaya combinations. Livestock like cattle (cow) and duck were reared on pond bund while makhana and fishery in pond. The cropping system on pond bunds includes three tier model of litchi cum banana/papaya and seasonal crop based system along with vermi-compost, livestock and makhana with fish culture in pond comprised with 4 models in 2000 m^2 area (Table 1).

Litchi cv. Shahi and China were planted on pond bunds with 6x6 m spacing during 2014 whereas banana cv. Grand Naine and papaya cv. Pune Selection-3 were planted at 2 m spacing as per different models in 2017. Fingerlings of *Pangasius* fish (locally known as *Jasar*) maintaining 8000/ha stocking density of 25-30 g were released in ponds during June and harvested in t March. Concentrate feed for fishes were purchased from market and expenditures on feed items were included in the cost of production. One vermi-compost unit was established to recycle the crop residue and cattle dung. One unit of cattle (2 cows) was also integrated to fulfil the milk and FYM requirement. Two months old five ducks (Khaki Campbell) was also introduced and sheltered in one fish pond which started laying eggs after 150 days. An improved cultivar of makhana was also integrated in one pond with fish culture. Seeds of makhana were sown during January and harvested after nine months of crop growth in October. Standard package of practices were followed for cultivation of litchi, banana, papaya, vegetables, field crops, makhana and rearing of duck, cattle and fishes (Kumar et al 2012). Soil sample collected from study site and analyzed at the beginning of experiment and 3 years after experimentation from pond bunds.

The comparative profitability, soil health and employment generation of different components in each model were compared across the different models for a period of three years to identify the suitability of model components, cropping sequence and sustainability of IFS. Profitability and employment generation of various components of each model were calculated individually and computed model wise. The labourers engaged for different activities in each component were recorded in terms of hours every day and converted into man-days/year. The involvement of labour for up keep in each enterprise under different models was considered for comparison, based on employment generation (man-days). The system economic efficiency (SEE) was calculated on the basis of net returns obtained from the system divided by 365 days (time year) (Mukherjee 2010). The sustainability is

Table 1. Allocation of area under different components in farming system (2000m^2 area under each model)

Farming system model	Components wise area (m^2)									
	Fish	Litchi	Banana	Papaya	Vegetables	Dairy	Vermi-compost	Duck	Field crop	Makhana
Model 1: Fish+litchi+banana+vegetables+dairy+vermi-compost	1200 (60)	180 (9)	220 (11)	-	150 (8)	225 (11)	25 (1)	Shelter on fish pond/bund	-	-
Model 2: Fish+duck+litchi+papaya+vegetables	1400 (70)	250 (12)	-	200 (10)	150 (8)	-	-	-	-	-
Model 3: Fish+litchi+banana+field crop	1500 (75)	200 (10)	150 (7)	-	-	-	-	-	150 (8)	-
Model 4: Fish+makhana+litchi+papaya+field crop	1600 (80)	175 (9)	-	125 (6)	-	-	-	-	100 (5)	Grown in pond with fish

Figure in parenthesis is percentage of area occupied in each component

expressed as sustainable value index (SVI). Sustainability values index for each model was calculated following the formula SVI = NR–SD/MNR (Bohra and Kumar 2015), where NR stands for net returns obtained under any model, SD stands for standard deviation of net returns of all models and MNR stands for maximum net returns attained under any model. The suitability and viability of model was identified for their existence based on their net returns, SVI and improvement in soil fertility attained over a period of time.

RESULTS AND DISCUSSION

Yield attributes: In model-1, fish component occupied 60% area followed by horticultural crops about 28% area and cattle (dairy) 8% along with a vermi-compost unit was set up to recycle the agro-waste into the system. The fish produced from the model-1 was in bigger size (850-1250 g) as compared to other model (650-950 g). Fish reared under this model attained bigger size could have got more nutritious feed due to liking of cow urine and litter residue material in pond. Growth of litchi plants cv. 'Shahi' and 'China' was quite vigorous and gave the fruit yield ranged from 20-28 kg/tree at 5 years after planting. Banana cv. 'Grand Naine' yielded 15.5-29.5 kg bunch weight in main as well as ratoon crop. Similarly, papaya yield ranged from 10.5 to 23.5 kg fruits/tree with average fruit weight of 0.80-1.48 kg/fruit. However, fruit weight depends on number of fruit per branch or plants (Lal et al. 2023a and b). Production of vermi-compost by using crop residues like banana pseudo stem, litchi leaves, and farm grasses has been done. It was observed that vermi-compost production from banana pseudo stem was faster than other residues due to easily decomposition and conversion into vermi-compost by the earth worm followed by farm grasses and litchi leaves. Two cross bread cow reared under model-1 produced average milk yield of 8.5-10.5 litre/day. Ducks (Khaki Campbell) reared under model-2 started laying eggs at 5 months of age and dropping of ducks were fed to fish reared in pond. The seeds of makhana were shown in pond with fish (model-4) maintaining of about 2.5-3 foot water depth throughout the growing period. The harvesting of makhana seed was done during October month and recorded 15.5 kg yield.

Table 2. Comparative performance of economics in different farming system models

IFS models	Components	Gross return (Rs.)	Cost of cultivation (Rs)	Net income (Rs)	Benefit : Cost ratio
Model 1	Fish	161000	110000	51000	1.46
	Litchi	3000	1000	2000	3.00
	Banana	2200	950	1250	2.32
	Vegetables	1900	750	1150	2.53
	Dairy	185000	140000	45000	1.32
	Vermi-compost	25000	6000	19000	4.17
	Total	378100	258700	119400	1.46
Model 2	Fish + Duck	170000	110500	59500	1.54
		3000	1200	1800	2.50
	Litchi	4200	1350	2850	3.11
	Papaya	1650	700	950	2.36
	Vegetables	2000	925	1075	2.16
	Total	180850	114675	66175	1.58
Model 3	Fish	171500	121250	50250	1.41
	Litchi	3600	1250	2350	2.88
	Banana	1550	625	925	2.48
	Intercropping	1750	925	825	1.89
	Total	178400	124050	54350	1.44
Model 4	Fish + Makhana	145500	110500	35000	1.32
		11500	1750	9750	6.57
	Litchi	3250	1100	2150	2.95
	Papaya	1125	450	675	2.50
	Intercropping	1450	750	650	1.93
	Total	162825	114550	48225	1.42

Economics: Integration of different components like fruit, seasonal vegetables, fish and dairy under model-1 found highly economical than other models in terms of net return (Table 2). In all the models major share of income received from fishery component. The highest income of Rs 119400in terms of net return was obtained in model-1 with maximum share of income obtained from fishery (42.71%), dairy (37.69%) and vermi-compost unit (15.91%). Model-2 recorded net income of Rs 66175 followed by model-3 (Rs 54350) and lowest in model-4 (Rs 48225). The highest share of net return (89.91%) was realized from fish and litchi fruit (4.31%). The net income under model-3 also recorded similar pattern to model-2 with major share from fish (92.46%) and litchi crop (4.32%) component. However in model-4, fish contributes the major share of net income but, as compared to other models realization of profit was less due to poor growth of fish recorded under this model which could be might be due to integration of makhana with fish would have hampered the growth of the fishes. The highest net return of Rs 35000 was obtained from fish followed by makhana (Rs 9750) and litchi (Rs 2150) under model-4. The higher benefit: cost ratio (1.58) was obtained with model-2 (followed by model-1(model-3 () and model-4). Though net return was higher and benefit: cost ratio was comparatively lesser in model-1 than model-2. This may be due to higher the expenditure incurred in model-1 due to cost of cows rearing. This higher expenditure on rearing of cattle was due to purchase of concentrate feed material from the market. Kumar et al (2011) also observed the similar pattern of obtaining the lesser B:C ratio under cattle component integrated with farming system in eastern India.

System economic efficiency and sustainable value index: The system economic efficiency (SEE varied among the models (Fig. 1). The higher SEE was with model-1 (Rs. 327/day). The trends of SEE were followed in the order of mode-1 > model-2 > model-3 > model-4. The inclusion of more suitable remunerative enterprises would increase the productivity and net income and thus provide the better SEE (Kumar et al 2015, Patel et al 2020b). Sustainable value index among the models varied due to different components (Fig. 1). They higher the value of SVI was associated with model-1 (0.73). The trends of SVI were followed in the order of mode-1 > model-2 > model-3 > model-4.

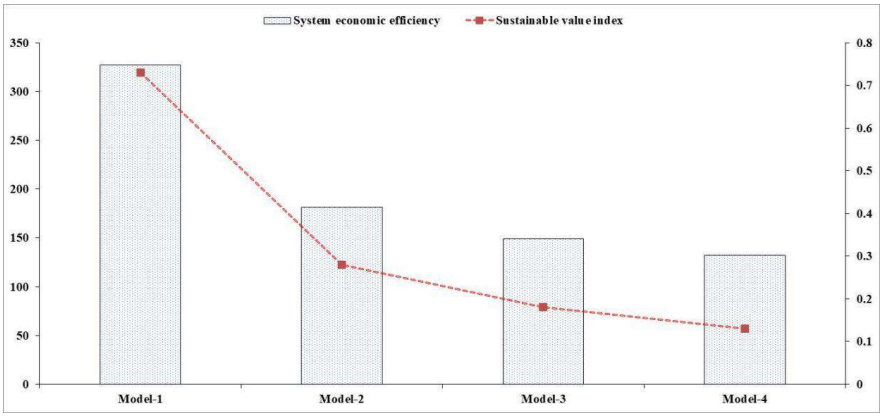

Fig. 1. System economic efficiency and sustainable value index of different IFS model

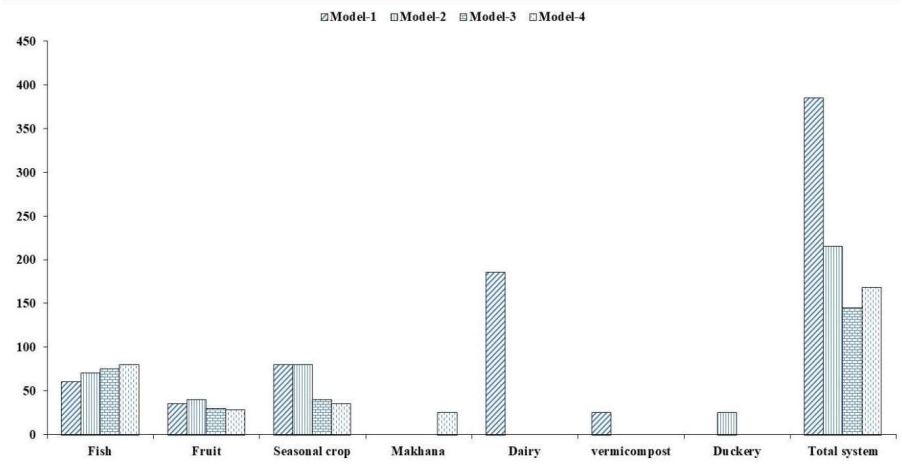

Fig. 2. Employment generation by different components under various farming system model (2000 m^2)

Table 3. Initial and final (parenthesis) soil health values

IFS Model	pH	EC	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Model-1	8.15 (8.00)	0.09 (0.11)	0.60 (0.78)	102.50 (116.52)	42.50 (45.58)	87.55 (100.15)
Model-2	8.00 (7.98)	0.10 (0.15)	0.62 (0.75)	105.25 (114.50)	41.25 (43.52)	91.00 (97.50)
Model-3	8.25 (8.10)	0.11 (0.16)	0.65 (0.70)	110.32 (117.25)	42.75 (45.50)	87.52 (94.50)
Model-4	8.28 (8.15)	0.10 (0.16)	0.65 (0.73)	103.25 (113.15)	40.82 (42.80)	89.25 (95.50)

Employment generation: Integration of different enterprises under farming system models had increased the employment opportunity on yearly basis (Fig. 2). The integration of fish, fruits, vegetable and dairy component in the system showed greater employment opportunity and it was almost double than the model-3 and model-4. The highest total system employment generation was observed in model-1 (385 man-days/year) followed by model-2 and model- 4. However, model-3 generated the least employment (145 man-days/year). Combining of livestock, vermi-compost and makhana cultivation with other enterprises would have increase the labour requirement and thus provide scope to employ more family labours round the year. Ravisankar et al (2007), Kumar et al. (2011) and Patel et al (2020b) also reported the similar trend.

Soil health: Soil sample collected from study site and analyzed at the beginning of experiment and 3 years after experimentation from pond bunds. Integration of different components in a system and recycling of by products and farm wastes has been practiced in all the models. Pseudo stem with leaves obtained as crop residues from banana, leaves and plant stump from vegetables and other seasonal crops were utilized for mulching of plant basin and also incorporated in to the soil during land preparation. There was marked improvement in soil health status (pH, EC, soil organic carbon and NPK) was observed as compared to initial soil status after completion of three years of study (Table 3 , 4). Soil pH was decreased slightly in all models after completion of 3 years. EC increased from initial value of 0.09-0.11 to 0.11 to 0.16 dsm^{-1} among the different models which indicates the positive effect of different components in amelioration of soil salinity. Soil organic carbon content (OC) was also markedly improved from 0.60 to 0.78, 0.62 to 0.75, 0.65 to 0.70 and 0.65 to 0.73% in model-1, model-2, model-3 and model-4, respectively. These significant changes were more pronounced, where seasonal crops integrated with livestock, fishery, and subsidiary component with respective IFS model. Similarly, all the major available nutrient i.e. NPK in soil after 3 years were improved markedly with all the four established model. However, recycling of organic manures obtained from different components added N, P_2O_5 and K_2O into system as a whole, which can minimize the dependency upon inorganic fertilizer up to some extent, provides good soil health on long-term basis. Acharya and Mondal (2010) reported residues recycling in each model revealed an integration of crop with allied components resulted in higher model productivity, profitability as well as soil health over years. Hence, results on integration of different components with crop in a system depending upon their suitability and preferences were found encouraging in agro-climatic condition of northern Bihar.

CONCLUSION

The integration of different components like fruit, seasonal vegetables, fish and dairy under model-1 (Fish+litchi+ banana+vegetables+dairy+vermi-compost) returned with highest net income of Rs 1,19,400 followed by model-2 (Fish+duck+litchi+papaya+vegetables) which recorded net income of Rs 66,175, and lowest in model-4 (two row of litchi + papaya in between two litchi plants + field crops and makhana with fishery) of Rs 48,225. The higher benefit: cost ratio (1.58) was obtained with model-2 followed by model-1 (1.46). The system economic efficiency and sustainable value index was higher in model-1 (Rs. 327/day and 0.73).

AUTHOR CONTRIBUTIONS

Conceptualization: RKP, Formal analysis: NL, AK. Investigation: RKP, KS, AK. Methodology: AK. Supervision: RKP, NL, AK, KS. Writing – original draft: RPK. Writing–review & editing: RKP, NL.

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Assessment of Onion Seed Quality Intercropped with Beet Leaf

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***Abstract*:** To investigate the efficient strategy for onion seed production in intercropping systems a field experiment was conducted at CCS HAU, Hisar in two *rabi* seasons (2018-19 & 2019-20). Onion was grown as the main seed crop while beet leaf an intercrop with different leaf cutting frequencies. The superior onion seed quality parameters were in sole onion treatment *i.e.,* test weight (3.73g), germination (79.7%), vigour I (1285.2), vigour II (137.5), tetrazolium (94.0%), electric conductivity (0.20 µS/cm/50 seeds) and accelerated ageing test (48.3%). Among intercropping treatments, the highest seed quality parameters were from combination, onion + beet leaf (1 row) with 3 cuttings *i.e.,* test weight (3.53g), germination(75.0%), vigour I (1187.1), vigour II (122.7), tetrazolium (92.0%), electric conductivity (0.21 µS/cm/50 seeds) and accelerated ageing test (46.3%). The minimum seed quality parameters were from combination, onion + beet leaf (2 rows) 3 cuttings and left for seed crop.

***Keywords*:** *Allium cepa* L. *Beta vulgaris*, Cutting frequency, Intercrop, Row pattern, Seed quality

Onion (*Allium cepa* L.), a member of the Alliaceae family is one of the most significant vegetable crops produced globally. The average productivity in India is 18.1 t/ha, and leads the world in terms of area (1.43 million hectare) and bulb production (26.74 million metric tonne) (Anonymous 2020). The ability of farmers to obtain better onion seed has previously been hampered by a lack of quality seed supply through the official system and lack of technical assistance for the promotion of informal seed systems on the other. Onion crop is being grown over a greater area, which is increasing the need for high-quality seeds (Chengappa et al 2012). Achieving productivity targets depends on having healthy, viable, highest standard seed available during planting that enhances crop productivity and yield by 10-15% (Gaur et al 2020). As it continues to lose viability after 1-1.5 years of storage in an ambient environment, onion seed is regarded as an orthodox and poor store in this regard (Pritchard and Nadarajan 2008). Promotion of seed production by the farmer to fulfil his seed requirement but low-quality seeds are the main constraint with onion crops because they cause sluggish and asynchronous germination as well as a significant proportion of aberrant seedlings (Borowski and Michaek 2006), so that seed production requires skills otherwise onion seed sold by private companies at very high rates. Since germination tests rely on pure seed components, purity analyses and germination tests complement one another (Haque et al 2007). Therefore, the purity analysis and germination tests must be considered to assess the real planting value of the seed. Beet leaf (*Beta vulgaris* var. bengalensis) is one of the most common green vegetables cultivated and consumed in India. It may be produced all year long and is well-liked for its high nutritional content, although the primary crop is typically taken from October to November. After seeding, its leaves are available for the first cutting around 35 days later and further cuttings are taken at intervals of 15-20 days (Kumar et al 2022). Intercropping has been used extensively because of its numerous advantages, which include optimum land utilization (Mohammed et al 2022), weed suppression (Rad et al 2020), advantageous ecosystem services, promoted pest management (Himmelstein et al 2017), and fertility of the soil enhanced performance via the fixation of nitrogen by the bacteria *Rhizobium* (Li et al 2014). Intercropping also has been regarded as a method to increase agricultural sustainability (Maitra 2020). The selection of an optimum intercrop mixture, population density, and intercrop planting geometry (Yang et al 2015) can all improve crop productivity and farmers income. The experiment was conducted to examine the impact of cutting frequency and row patterns of beet leaf on onion crop seed quality in intercropping and to optimize their crop production.

MATERIAL AND METHODS

Experimental details: The field experiment was conducted at CCS Haryana Agricultural University, Hisar, which is situated at 29° 10' latitude north, 75° 46' longitude east, and 215.2 m above mean sea level in the subtropical climate zone of India. Field experiment was conducted during the *rabi*

season 2018-19 and 2019-20 in a randomized block design and replicated three times. The onion variety selected was Hisar onion 3 (HO-3) and the beet leaf variety HS 23. Recommended package of practices followed for optimum growth of both the crops (Anonymous 2021). Seed was harvested when 50% of black seeds were exposed on an umbel, dried and threshed manually. Different seed quality parameters like test weight, standard germination (SG) test (%), tetrazolium (Tz) test (%), seed vigour index-I & II, accelerated ageing (AAT) test (%) and electric conductivity (EC) test (µS/cm) were performed. The data were statistically analyzed using the OPSTAT software.

Test weight (g): This was based on one thousand (1000) randomly selected seeds from the seed lot of each treatment per replication.

Standard germination test (%): For the standard germination test, 50 randomly selected seeds from every treatment per replication were placed in germination papers inside the germination chambers set at 25± 1°C and on the 14th day germination was counted.

Tetrazolium (Tz) test: To performing the tetrazolium staining test seeds were sliced longitudinally through the midsection of the distal half, then placed in petri dishes with 2.5 ml of 1% solution by mass of 2,3,5 triphenyl tetrazolium chloride. After a 24-h staining time in the germination chamber, seeds that displayed a completely stained embryo and white endosperm were classified as viable (ISTA 1999). The percentage of viable seeds after tetrazolium staining was calculated as the total number of viable seeds.

Vigour indices: At the time of counting the standard germination, 20 normal seedlings per replication were randomly selected. The length of the shoot was measured from the tip to the end of the shoot and the length of the radical was measured from the tip of the root to the end of the root, in centimetres and the average length was calculated. Its fresh weight (FW) and dry weight (DW) of 20 seedlings was observed. Seedlings were dried in a hot air oven for 24 h at 80 ± 1°C. The dried seedlings of each replication were weighed for dry weight of seedling of each treatment. Seedling vigour indices were calculated according to the method suggested by Abdul-Baki and Anderson (1973).

Seed vigour index I = seed germination (%) × average seedling length (cm)

Seed vigour index II = seed germination (%) × average dry seedling weight (mg)

Electrical conductivity (EC) (µS/cm): Fifty seeds selected randomly from each seed lot were soaked in beakers each containing 75 ml of distilled water. The seeds were immersed completely in water and the beakers were covered with foil. Thereafter, these samples were kept in the germinator at 25 + 1°C for 24 hours (h). The electrical conductivity of seed leachates was measured by 60 direct reading conductivity meters. The conductivity was expressed in µS/cm/seed.

Accelerated ageing (AAT) Test (%): For testing the accelerated ageing under artificial conditions, 2 grams of freshly harvested seeds for each of three replications were taken and were put on the stainless-steel mesh into a plastic box with distilled water in the bottom and placed in an accelerated ageing chamber at 40 ± 1°C and about 100% RH for 48 hours. After the incubation, 50 randomly selected seeds were tested for germination, as per the ISTA. Accelerated ageing percentage was calculated by just counting the normal seedlings after germination in the germinator as per the standard germination percentage.

RESULTS AND DISCUSSION

Onion seed yield (q/ha): The onion seed yield was influenced by the beet leaf intercropping systems when compared with the onion sole crop. This variation might be due to higher plant population in intercropping treatments and more competition for resources *i.e.,* land, water, space and nutrients as compared to the sole onion crop (Table 1). The maximum seed yield (5.81q ha^{-1}) was in T1. The Intercropping treatment (T2) resulted in seed yield reduction when compared to onion sole crop (T2: 4.87 q ha^{-1} and T1: 5.81 q ha^{-1}). The seed yield was further reduced when the number of beet leaf rows was increased (1 to 2 rows) *i.e.,* T9 (4.80q ha^{-1}) as compared to T1 and T2. The minimum seed yield was from T10 (3.29q ha^{-1}). The significant seed yield reduction was T9, because the beet leaf was also left for seed with onion seed crop in an earlier stage, under these conditions beet leaf crop grew taller than the onion crop and influenced the onion seed yield by shedding effects. The number of rows and cuttings frequency of beet leaf also influenced the onion seed yield and may due to the negative shading effects of beet leaf on onion crop plants due to more height of beet leaf crop as the treatment was left for seed after 3rd or 4th cuttings. The beet leaf did not show shading effects on the onion umbels rather than crop competitions when was left for seed crop after 5th leaf cutting. The yield reductions might be also due to spatial competition, nutritional competition, waster stress and few numbers of honey bee visits for doing pollination in high-density plant populations under intercropping conditions. Liu et al (2016) also reported that population density and intercropping of sorghum and soybean may alter their growth and yield patterns through responses to light and physiological attributes as compared to their performance in standard densities and sole crop conditions. Obadoni et al (2005) observed from the intercropping mixtures that the yield of tomato was

consistently greater in plots containing higher and equal proportions of tomato with cowpea, while cowpea yield was highest in its sole treatments and also performed well when combined with 67% cowpea and 33% tomato. Singh and Kushwaha (2012) reported that intercropping radish or spinach with potatoes decreased potato output by 17% and 8%, respectively. This could be a result of intercrop competition for the potato, which would reduce per-plant production and affect total tuber yield.

Test weight (g): The superior test weight (3.73g) was recorded from the T1 (sole onion seed crop). In the intercropping treatments the highest test weight (3.53g) was in T2 followed by treatment T9 (3.48g). The minimum test weight (2.59g) was in T10. The cutting frequency and the number of beet leaf rows influenced the onion test weight in the intercropping patterns. There was no significant reduction in onion test weight at minimum frequency leaf cuttings (3 cutting) and uprooting of the beet leaf crop compared to minimum leaf cutting and left for seed crop. This might be due to the reduced crop's competition by uprooting the beet leaf after 3rd cutting, and from now the crop grew as a sole crop. So, these treatments (T2 and T9) performed the test weight as like sole onion seed crop. The test weight of the onion was further reduced in the subsequent cuttings from the 3rd to 6th beet leaf cutting. These results indicate that minimum leaf cutting leads to more test weight and furthermore cutting leads to reduced test weight, which might be due to the different crop competitions. The test weight of onion was significantly reduced when beet leaf crop was also left for seed with onion seed crop in intercropping. It was significantly reduced in T3 and T10 of 3 leaf cutting and left for seed crop followed by treatments of 4th and 5th leaf cuttings. Two-row treatments always influenced test weight as compared to the one-row treatment on the same frequency of leaf cuttings. Huang et al (2019) also reported that intercropping system and their yield are closely related to planting density and 100 grain weight.

Standard germination (%): Among intercropping treatments, the maximum standard germination percentage was in T2 (75%). The test standard germination results amongst the intercropping treatments might be due to single row and earliest uprooting (after 3rd cutting) of the beet leaf crop responsible for reducing the competition for nutrients, light, space and better photosynthetic accumulations under the field conditions and enhanced the seed storage ingredients. The treatment was at par with two-row treatment T9 (74%) on the same frequency of beet leaf cutting (Table 1). Minimum standard germination was recorded from the treatment T10 (58.3%). This minimum standard germination percentage might be due to higher crops' competition for nutrients, sunlight and space, and most are the shading effects of beet leaf on onion umbels. Improper seed development resulted in a low accumulation of food reserves, which ultimately led to inferior germination under laboratory

Table 1. Effect of cutting frequency and beet leaf rows on seed yield, test weight, standard germination test and vigour index-I of onion seed produced in intercropping (Pooled)

Treatments↓ / Quality parameters of onion seed →	Seed yield (q/ha)	Test weight (g)	Std. germination (%)	Vigour index I
T_1: Onion seed crop (sole crop)	5.81	3.73^{a}	79.7	1,285.20
T_2: Onion + Beet leaf (1 row) with 3 cuttings	4.87^{a}	3.53^{ab}	75.0^{a}	1187.1^{a}
T_3: Onion + Beet leaf (1 row) 3 cuttings and left for seed crop	3.41^{e}	2.74^{k-m}	60.0^{lm}	818.6^{lm}
T_4: Onion + Beet leaf (1 row) with 4 cuttings	4.74^{b}	3.42^{b-d}	72.0^{bc}	1122.8^{a-c}
T_5: Onion + Beet leaf (1 row) 4 cuttings and left for seed crop	3.61^{d}	2.82^{i-l}	64.3^{i-k}	931.5^{i-k}
T_6: Onion + Beet leaf (1 row) with 5 cuttings	4.36^{c}	3.32^{b-f}	70.7^{c-e}	1078.4^{c-e}
T_7: Onion + Beet leaf (1 row) 5 cuttings and left for seed crop	3.88	2.98^{h-j}	66.0^{f-i}	971.0^{f-i}
T_8: Onion + Beet leaf (1 row) with 6 cuttings	4.16	3.12^{f-h}	68.0^{fg}	1028.8^{d-g}
T_9: Onion + Beet leaf (2 rows) with 3 cuttings	4.80^{ab}	3.48^{bc}	74.0^{ab}	1160.5^{ab}
T_{10}: Onion + Beet leaf (2 rows) 3 cuttings and left for seed crop	3.29	2.59^{m}	58.3^{m}	776.8^{m}
T_{11}: Onion + Beet leaf (2 rows) with 4 cuttings	4.49	3.36^{b-e}	71.0^{cd}	1097.4^{b-d}
T_{12}: Onion + Beet leaf (2 rows) 4 cuttings and left for seed crop	3.46^{e}	2.76^{k-m}	62.3^{kl}	889.0^{j-l}
T_{13}: Onion + Beet leaf (2 rows) with 5 cuttings	4.29^{c}	3.25^{d-g}	68.3^{ef}	1039.6^{d-f}
T_{14}: Onion + Beet leaf (2 rows) 5 cuttings and left for seed crop	3.66^{d}	2.90^{i-k}	65.3^{h-j}	953.6^{h-j}
T_{15}: Onion + Beet leaf (2 rows) with 6 cuttings	4.04	2.99^{hi}	67.3^{f-h}	1008.9^{e-h}
CD (p=0:05)	0.08	0.21	2.6	70.5

q - Quintal, ha - Hectare, wt. - Weight, g - Gram, Std. - Standard

conditions. Whereas superior standard germination was observed in sole onion crop T1 (79.7%) compared to the intercropping treatments, the best results might be due to crop autonomy. The data revealed that the onion seed produced in one-row patterns and low-frequency cutting (3 or 4 cutting and uprooting) beet leaf resulted in significantly higher standard germination percentages (tested in the laboratory) as compared to seed produced on the same frequency cuttings (3 or 4 cutting) and left for seed (same trend as test weight). In these treatments, the standard germination of onion seed was significantly reduced. The higher plant population, or intercropping, reduces seed vigorousness and seed germination. Gowda et al (2020) also reported that significantly high seed germination, seedling length and dry weight, vigor index I and II and lower EC in sole chickpea compared to the intercropping treatments.

Vigour index I: The maximum vigour index I was recorded from intercropping treatment T2 (1187.1) followed by T9 (1160.5). The T10 recorded minimum seed vigour I (776.8), A higher vigour index reflects healthy or best-quality seeds, and a lower vigour index reflects inferior-quality or unhealthy seeds. More crop competition under field conditions reduces the seed quality, as the beet leaf crop left for seed after the 3rd cutting, which grew taller than the onion crop, was responsible for the shading effect on onion seed umbels. Furthermore, two rows of beet leaf between the onion lines increase the plant population density, exerting different types of crop competition and ultimately reducing the seed vigour index I. The superior vigour index-I of sole onion treatment T1 (1285.2) might be due to low population density and the absence of crop competition. Similar results were also reported by Gowda et al (2020). Vigour index follows the same trend (Table 1).

Vigour index II: The maximum seed vigour II was in T2 (122.7) and T10 resulted in the minimum (65.7) vigour II among the intercropping treatments. Treatment T1 (sole onion) resulted in the highest vigour index II (137.5) among the other intercropping treatments (Table 2). The best seed vigour index results in sole onion might be due to more seed reserve accumulation under less plant population density in the absence of any type of competition and highly vigorous seeds. But under the intercropping treatments, the planting density reduced the seed vigour and seed quality. After uprooting the beet leaf crop after a few cuttings (after 3rd cutting), the treatments performed as sole onion seed crops after only slight influences.

Tetrazolium (Tz) test: The results of the tetrazolium test revealed that the maximum test percent was in T2 (92%) and was regarded as the more vigorous and healthy seed. The minimum was recorded in T10 (71.3%), which shows more dead embryos, less vigorous seed, and inferior seed quality. The T1 recorded superior Tz test results (94%) concerning the other intercropping treatments and having highly vigorous and healthy seeds with higher germination

Table 2. Effect of cutting frequency and beet leaf rows on seed vigour index II, tetrazolium test, electric conductivity (ECe) and accelerated ageing test (AAT) of onion seed produced in intercropping (Pooled)

Treatments	Vigour index II	Tz Test (%)	ECe (µS/cm)	AAT (%)
T_1	137.5	94.0^{a}	0.20^{a}	48.3^{a}
T_2	122.7^{a}	92.0^{ab}	0.21^{ab}	46.3^{ab}
T_3	69.3^{kl}	74.0^{kl}	0.39^{lm}	31.7^{ij}
T_4	113.3^{a-c}	90.0^{a-d}	0.23^{a-d}	44.3^{b-d}
T_5	78.8^{i-k}	76.7^{i-k}	0.35^{i-k}	32.7^{ij}
T_6	105.1^{c-e}	88.7^{b-f}	0.25^{c-f}	40.3^{ef}
T_7	87.4^{f-i}	80.7^{i}	0.33^{hi}	34.3^{i}
T_8	95.2^{e-g}	86.0^{d-h}	0.28^{fg}	38.3^{f-h}
T_9	120.7^{ab}	91.3^{a-c}	0.22^{a-c}	45.3^{bc}
T_{10}	65.6^{l}	71.3^{l}	0.41^{m}	30.7^{j}
T_{11}	110.1^{b-d}	89.3^{b-e}	0.24^{b-e}	43.0^{c-e}
T_{12}	76.6^{i-l}	75.3^{jk}	0.36^{i-l}	33.3^{ij}
T_{13}	98.2^{ef}	86.7^{d-g}	0.25^{c-f}	38.3^{f-h}
T_{14}	85.0^{g-j}	78.7^{ij}	0.34^{ij}	33.0^{ij}
T_1	91.0^{f-h}	85.3^{e-h}	0.30^{gh}	37.3^{gh}
CD (p=0:05)	11.5	4.5	0.03	2.8

Tz -Tetrazolium, EC- Electric conductivity, AAT - Accelerated ageing test; See Table 1 for details

possibility under field conditions due to more alive embryos in seeds (Marcos 2015).

Electric conductivity (ECe) test: The electric conductivity is negatively correlated with the quality and vigour of the seed. Lower seed EC readings represent positive or better test results whereas maximum readings show worse seed quality results. The minimum electric conductivity was in the sole onion seed crop treatment T1 (0.20 µS/cm/50 seeds) and was at par with T2 (0.21 µS/cm/50 seeds), which was an intercropping treatment. The seed quality was considered good and healthy under the seed standards. The maximum electric conductivity (0.41 µS/cm/50 seeds) was in T10, which was regarded as having the lowest seed vigour and unhealthy seed standards. The results indicated that the number of rows and cutting frequency of the beet leaf crop, along with the left for the seed crop, also influenced the electric conductivity of onion seed while influencing quality.

Accelerated ageing test (AAT): The maximum germination (46.3%) was in T2 after inducing under artificial environmental conditions in the intercropping treatments. This minimum ageing and maximum germination rate results in the seed being considered vigorous and of good quality. The minimum germination (30.7%) was in T10 after artificial ageing which was considered a poor seed with less storage ability, superior germination (48.3%) from the sole onion crop (T1) was recorded amongst all the treatments after the artificial ageing. The superior germination of the sole onion seed crop might be due to the most vigorous, healthy, and best quality seed produced in single crop conditions. This seed was regarded as having good storage ability for a longer duration. The figures for accelerated ageing with similar superscripts are significantly not different (Table 2). Intercropping influenced the seed ageing test results, but the intensity of the influence depends upon the number of rows, frequency of cutting, and taking of the seed crop of the beet leaf.

The seed quality parameters of onion that the treatments followed the different quality trends under different intercropping combinations but similar trending patterns were observed in all the seed quality parameters. The seed quality parameters were gradually influenced by the cutting frequency and row patterns or population intensity under intercropping systems. The uprooting of the beet leaf crop after few leaf cuttings resulted in improved seed quality of onion and also fulfilled the minimum required seed quality standards. Slightly but not significantly the row pattern (one-row and two-rows) also influenced the seed quality parameter at the same frequency of cutting but not more than the cuttings frequency. The seed quality parameters of onion were significantly reduced when the beet leaf crop produced seed in the same treatment as the onion seed. In the treatments in which the beet leaf was left for the seed after a few leaf cuttings (3^{rd} and 4^{th} cutting), the seed quality parameters were significantly reduced and could not fulfil the minimum quality standards of the seed, especially the standard germination. This inferior seed quality might be due to the higher plant population intensity, shade effect of beet leaf crop on onion umbels and more crop competition. Due to these circumstances, a low amount of photosynthates accumulates in the seed's reserve. This higher cropping intensity was also responsible for more fungal and bacterial disease infections that made the plant weak and sick. Wekesa et al (2015) reported that pure stands yielded significantly higher yields than intercrops and suitable quality attributes to be used as seed. Gangadhar et al (2018) reported that significantly higher oil yield and oil content of safflower were recorded with their pure stands of the crops. But when compared with the different intercropping systems, the highest oil yield of safflower was recorded in safflower + linseed (1:2) 30 cm rows (374 kg ha^{-1}), and the highest oil content was recorded in safflower + linseed (1:1) 30 cm rows (30%). Seed deterioration often begins as the seeds continue to dry out to the harvest maturity stage after reaching physiological maturity (Delouche 2021). The basic quality of seed was determined by the degree and severity of field degradation (*i.e.*, weathering); except for rare conditions, seed quality may be maintained during harvest and subsequent procedures but cannot be improved beyond the level at harvest. Oshone et al (2014) studied the physical, physiological, and health qualities of common bean seed produced by smallholder farmers using sole crop and intercropping systems. All samples of seed obtained from sole and intercropping cropping systems met the national seed standard for a common bean seed (95%) with pure seed proportion above 98%. The most prevalent bacterial and fungal ailments associated with the seed samples were common bacterial blight and *Aspergillus flavus*. The farmers could grow and use seed produced under sole and intercropping systems in places with limited agricultural land as long as the proper production and post-harvest management procedures were followed.

Correlation coefficients: The estimates of correlation coefficients among different characters have been presented in. The results of correlation studies showed that seed yield /plant, seed yield ha^{-1}, and test weight exhibited highly significant and positive with seed quality parameters (Table 3). The correlation coefficient was highly significant and positive correlation. The seed yield per plant revealed and exhibited highly significant and positively correlated with standard germination (0.961), seedling length (0.895),

Table 3. Estimation of correlation coefficients between seed yield with seed quality parameters of onion in intercropping

Seed quality parameters	YP^{-1}	Y ha^{-1}	Test wt.	Std. G	SL	SF wt.	SD wt.	V-I	V-II
Seed yield /plant (g)	1	-	-	-	-	-	-	-	-
Seed yield (q/ha)	0.973**	1	-	-	-	-	-	-	-
Test weight (g)	0.955**	0.973**	1	-	-	-	-	-	-
Std. germination (%)	0.961**	0.978**	0.982**	1	-	-	-	-	-
Seedling length (cm)	0.895**	0.926**	0.964**	0.973**	1	-	-	-	-
Seedlings' fresh wt. (mg)	0.912**	0.943**	0.970**	0.972**	0.971**	1	-	-	-
Seedlings' dry wt. (mg)	0.959**	0.968**	0.993**	0.984**	0.968**	0.972**	1	-	-
Vigour index-I	0.952**	0.972**	0.982**	0.998**	0.984**	0.975**	0.985**	1	-
Vigour index-II	0.975**	0.983**	0.991**	0.993**	0.963**	0.968**	0.996**	0.991**	1

YP^{-1}- Seed yield per plant, Y ha^{-1}- Yield per hectare, Test wt. - Test weight, Std. G- Standard germination- SL- Seedling length, SF wt.- Seedlings fresh weight, SD wt.- Seedlings dry weight, V-I- Vigour index-I, V-II- Vigour index- II, **Significant level at (p = 0.05)

seedling fresh weight (0.912), seedling dry weight (0.959), and seed vigour index-I (0.952) and seed vigour index-II (0.975). Such relationships suggested that high values for standard germination, seed vigour index-I, seed vigour index II, seedling fresh and dry weight could be assumed for intercropping systems that additionally had high seed yield per plant, seed yield per hectare and weight of the thousand seeds. Basaiwala et al (2013), and Panwar et al (2018) also found a highly positive correlation between seed vigour indices, seedling fresh weight, seedling dry weight, and standard germination with seed yield per plant seed yield ha^{-1} relationship in vegetable pea.

CONCLUSION

The yield and quality standards of onion seed depend upon row patterns and cutting frequency along with the seed production of beet leaf. The seed produced under sole crop conditions was best in yield and quality parameters and also fit the minimum seed quality standards. The decision to intercrop beet leaf with onion affects the farmer's yield and quality of seed and could affect his income as intercropping influences the seed yield. However, the seed produced under intercropping conditions could fulfill the minimum seed certification standards, accepting a few treatments where the beet leaf crop was also involved in seed production with onion crops.

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Germination and Vigour Enhancement through Combined Application of Osmo-priming and Organic Seed Pelleting in Carrot (*Daucus carota* L.)

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***Abstract*:** The objective of the current study was to examine the effect of seed priming and pelleting on germination and vigour in European carrot cv. Early Nantes. The carrot seed primed for 4 days in PEG 6000 solution with an osmotic potential of -1.2 MPa (P_4) had the highest germination, seedling length, seedling dry weight, seedling vigour index-length, seedling vigour index-mass and speed of germination. Among the pelleted seeds, *Melia azedarach* leaf powder pelleted seeds showed maximum values for parameters *viz*., germination, seedling length, seedling dry weight, seedling vigour index- length, seedling vigour index- mass and speed of germination. The combined application of seed priming for 4 days in PEG 6000 solution having osmotic potential of -1.2 MPa and pelleted with *Melia azedarach* leaf powder showed greater value for most of the seed quality parameters and enhanced the germination and vigour in carrot.

***Keywords*:** Germination, Seed vigour, Priming and pelleting of seeds, Seed quality, Carrot

Carrot (*Daucus carota* L.) a popular winter season root vegetable of the Umbelliferae family primarily originates from Afghanistan (Rubashevskaya 1931). The compound umbel inflorescence, a characteristic feature of the Umbelliferae family results in non- uniformity in seed size and seed quality. Carrots often have very extended vegetative and flowering periods. The flowers are produced at various mother plant locations, and the seeds are produced at various plant developmental stages. As a result, seeds of various seed qualities are produced. The position of the seeds on the mother plants determines the maternal type of heterogeneity, which commonly occurs (Panayotov 2005). Seed sowing is also hindered due to the presence of the beard on carrot seed rendering it difficult for machine as well as manual sowing and also carrot seed emergence and stand establishment are usually erratic and delayed. These inherent issues with the carrot seed lot causes uneven crop stand and plant growth.

Seed priming is a pre-sowing treatment of seeds that creates a physiological condition more favorable for better and even seed germination. In the early phases of germination, seed priming regulates hydration, which initiates the regular metabolic process prior to the radicle protrusion (Johnson and Puthur 2021). On the other hand, seed pelleting with different leaf powder can slow down the irreversible process of seed deterioration during storage. The leaf powders' anti-oxidant, fungicidal, and insecticidal qualities aid in the retention of the seed quality during storage. Seed priming complemented with seed pelleting maintains the desired seed size and smoothen the seed surface thus evading seed bearding in carrot. Seed quality is also enhanced through seed pelleting by the presence of additives *viz.* filler material like botanical leaf powder (Prakash et al 2018). Seed priming initiate various physiological and biochemical processes leading to seed germination. A special benefit is provided to seeds by pelleting in combination with priming technology, which promotes quicker, more uniform germination, and strong seedling growth (Weissmann et al 2022). Along with seed pelleting, primed seeds have multiple role of advancing stage of seed germination and improving seedling performance in horticultural crops. By quick and uniform germination rate, it also prevents seed losses and may result in lesser cost of cultivation. The present investigation was taken up to study the effect of seed priming and pelleting on seed germination and vigour characteristics in carrot.

MATERIAL AND METHODS

Experimental detail: The laboratory experiment was conducted during 2017 by adopting completely randomized design factorial at Dr YSPUHF, Solan (HP).Seeds of Early Nantes, a variety of European carrot were used for the current study. Freshly harvested carrot seeds were graded by using round-holed sieves by shaking manually to remove

the small seeds and other impurity from the seeds. This experiment comprised five priming treatment of polyethylene glycol *viz.,*PEG 6000 -1.0 MPa 2 days (P_1), PEG 6000 -1.0 MPa 4 days (P_2), PEG 6000 -1.2 MPa 2 days (P_3), PEG 6000 -1.2 MPa 4 days (P_4) and control (non-primed) (P_5). Seven different pelleting treatments were applied to each of the five primed seed lots. The carrot seeds were pelleted with *Lantana camara*leaf powder + clay (PL_1), *Eucalyptus* species leaf powder + clay (PL_2), *Melia azedarach*leaf powder + clay (PL_3),*Vitex negundo* leaf powder + clay (PL_4), clay alone (PL_5), Gum Arabica (PL_6) and unpelleted seed (PL_7) was considered as control. Except for the control, gum acacia was used as an adhesive for all pelleting treatments. So the experiment encompassed 35 treatment combinations.

Seed Priming

Preparation of priming solution*:* Polyethylene glycol 6000 (PEG 6000) solution of different osmotic potential -1.0 MPa and -1.2 MPa were used for priming. PEG -1.0 MPa solution was prepared by dissolving 284 g of PEG 6000 in 1 liter of water and PEG 6000 -1.2 MPa solution, 314 g of PEG 6000 in one liter of water**.** The concentration of the PEG 6000 solution was calculated using the Michel and Kaufmann (1973) equation:

$$\psi = (-(1.18 \times 10^{-2})C - (1.18 \times 10^{-4})C^2 + (2.67 \times 10^{-1})CT + (8.39 \times 10^{-1})C^2T) * 10^{-1}$$

Where,

C is the PEG concentration in g kg^{-1} of H_2O and T is the temperature in °C.

Priming procedure: Seeds of carrot were primed in polyethylene glycol (PEG 6000) solution of different osmotic potential of -1.0 MPa (284 g L^{-1}) and -1.2 MPa (314 g L^{-1}) at 20ºC for two and four days. PEG 6000 solutions with varying osmotic potential were stirred at a regular interval to promote aeration during priming. The moisture content of the seeds during priming process was 40-45% fresh weight basis. Primed seeds were rinsed in distilled water for two minutes after priming, and then surface dried using blotter paper and the primed seeds were dried back to original moisture content (10%). The moisture content of primed seeds was determined in by oven method at 105±3^{0}C for 24 hours (Brasil 1992).

Seed pelleting: For seed pelleting different botanicals leaves were collected from university campus and nearby areas. The leaves were powdered using a grinder and fine leaf powder was obtained by sieving through 0.10 mm wire mesh after grinding. Clay was employed as a filler material, botanical leaf powder was blended with clay in a certain ratio (1:4 by volume) and gum arabica (5%) was used as an adhesive. The seed pelleting process was carried out using SATEC equipment. The seven different pelleting treatments were applied to each of the five primed seed lots. For an efficient and homogeneous coating, 50 g of seeds were placed in a revolving drum and a mixture of filler materials and botanical powder acting as an inert substance sprinkled on seed in rotating drum. In relation to the amount of seed, the thickness of the pelleted seed is determined by the adhesive content. Therefore, the required amount of pelleting mixture was uniformly applied to the seed. The seeds of 3 mm size were pelleted and dried in the shade for two days.

Seed germination and vigour: Immediately after seed priming and pelleting seed quality characteristics were recorded. For analyzing germination and other vigour characteristics, the observations were made by using a *between paper method*, whereas speed of germination was computed by *top on paper* method. According to ISTA (2010) recommendations, 100 seeds of each treatment combination in four replication were germinated in *between paper* (B.P.) media by following placement of the rolled paper towel in the BOD germinator at 20° C. On the 14th day after the completion of the germination period, only normal seedlings were counted. In accordance with the standard protocol (ISTA 2010) the germination was evaluated as, normal seedlings, dead seed, abnormal seedlings.

$$\text{Germination percent} = \frac{\text{Total number of normal seedlings germinated}}{\text{Total number of seed}} \times 100$$

Ten normal seedlings from each replication of each treatment were randomly selected on the 14th day of germination testing and seedling length were measured by measuring scale in centimeter. Seedlings were dried in an oven for 24 hours at 80° C. to determine seedling dry weight. The seedling vigour index-length was calculated by using the formula *viz.,* Standard germination (%) x Seedling length (cm) and the seedling vigour index- mass was calculated: Standard germination (%) x Seedling dry weight (g) (Abdul-Baki and Anderson 1973). Based on Maguire (1962), the speed of germination was computed:

$$\text{Speed of germination} = \frac{X_1}{Y_1} + \frac{X_2 - X_1}{Y_2} + \cdots\cdots\cdots + \frac{X_n - X_{n-1}}{Y_n}$$

Where; X_1 , X_2 and X_n are number of seeds germinated on first , second and nth day, respectively and Y_1, Y_2 and Y_n are number of days from sowing to first, second and nth count respectively. Speed of germination is measured by top of paper method. The critical difference at a 5% level of significance was computed to compare the mean value of different treatments.

RESULTS AND DISCUSSION

Germination: Germination percent due to the effect of different priming and pelleting treatments in carrot seeds differed significantly (Table 1). The highest germination (86.05 %) was observed in PEG 6000 -1.2 MPa for 4 days primed seed (P_4), followed by PEG 6000 -1.0 MPa for 2 days primed seed (P_1) and the lowest germination (76.71 %) was observed in non-primed seed (P_5). Among the pelleted seeds, the highest germination (88.60 %) was in *Melia azedarach* leaf powder pelleted seeds (PL_3) over (PL_7) unpelleted seed. Combined effect of both priming and pelleting indicated that treatment combination of PEG 6000 -1.2 MPa for 4 days primed seed and pelleted with *Melia azedarach* leaf powder (P_4 x PL_3) resulted in highest germination (93.50 %)), which was at par with PEG 6000 -1.2 MPa for 2 days primed seed with *Vitex negundo* leaf powder(P_3 x PL_4) pelleted seed . However, the lowest germination (66.00 %) was recorded in treatment combination P_5x PL_7 (Control). Seed priming and seed pelleting both enhanced seed germination and vigour of carrot seeds. The osmopriming improves germination in carrot seed. In addition to its role in increasing the rate of seed germination, osmo priming activates synthesis of enzymes including DNA and RNA and mobilizes reserve food material. It also causes rapid expansion in development of embryo and removes hindrances in germination. These findings are in agreement with the findings of Sadeghi et al (2011) in Soybean, Dorna et al (2014) in pansy, Govinden-Soulange and Levantard (2008) in tomato and Kumar et al (2017) in chick pea. The increased seed germination in seeds pelleted with various botanicals may be due to higher moisture holding potential of colloids and higher protoplasm viscosity leading to permeable cell membrane that promote easier moisture entry, activating the quick seed's reserve food material hydrolysis in comparison to untreated seeds. Prakash et al (2018) observed the enhanced seed germination due to pelleting in black gram seed by pungum leaf powder. Pelleting of seeds with different leaf powders had also caused enhanced germination in chilli (Jerlin et al 2008), okra (Ramesh and Muthukrishnan 2015) and red gram (Anbarsan et al 2016).

Seedling length: The effect of both priming and pelleting on mean seedling length varied significantly, the highest seedling length (16.70 cm) was in the PEG 6000 -1.2 MPa for 4 days primed seed (P_4) followed by PEG 6000 -1.0 MPa for 4 days primed seed (P_2), as opposed to the shortest seedling length (14.64 cm) in unprimed seed (P_{14}). Among pelleted seeds, P_3 resulted into highest seedling length (18.32 cm) whereas, the lowest seedling length (14.56 cm) was in unpelleted seed (PL_7). Interaction effects revealed that treatment combination P_4 x PL_3*i.e.*PEG 6000 -1.2 MPa for 4 days primed seed with *Melia azedarach* leaf powder resulted in production of the longest seedling (20.30 cm). However, the smallest seedling length (11.40 cm) was observed in combination, P_5x PL_7 *i.e.* non primed unpelleted seed (Table 2).

Seeds primed with PEG solution results in elevated levels of various enzymes viz, catalases, peroxidase, amylase, and invertase in seeds, increased levels of RNA, sugar and protein causing higher length of seedling. Zheng et al (2015) observed better germination and faster growth by virtue of enhanced amylase and total soluble sugar both under normal and drought situations. Similar results have been observed for greater seedling length in bitter gourd (Thirusenduraselvi and Jerlin 2009) and in cucumber (Lima and Filho 2010). The enhanced seedling length in botanical leaf pelleted seeds might be due to the activity of numerous growth promotors and transfer of secondary metabolites to the growing seedling. These are in agreement with the report by Satish kumar et al (2014) in brinjal, Ramesh and Muthukrishnan

Table 1. Effect of combined application of seed priming and pelleting on germination (%) in carrot cv. Early Nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	87.50	80.00	80.50	80.00	78.00	81.20
*Eucalyptus*species + clay (PL_2)	87.00	77.00	78.00	85.50	84.50	82.40
Melia azedarach + clay (PL_3)	87.50	89.00	85.00	93.50	88.00	88.60
Vitex negundo + clay (PL_4)	79.50	77.50	92.50	87.50	76.50	82.70
Clay (PL_5)	83.30	77.00	74.50	84.85	66.50	77.23
Gum arabica (PL_6)	85.50	79.50	78.50	87.50	77.50	81.70
Control (Unpelleted) (PL_7)	75.28	76.50	75.50	90.50	66.00	76.76
Mean	83.65	79.50	80.64	87.05	76.71	

CD (p=0.05) =P- 0.96, PL-1.14, P x PL-2.55

(2015) in okra and chilli, and Prakash et al (2018) in black gram. Confirmatory revealed that antifungal and antioxidant effect of the botanicals in controlling physiological deterioration of seeds and translocation of nutrients to the heterotrophic seedling (Panwar et al 2023).

Seedling dry weight: Priming and pelleting treatment applied to carrot seeds also significantly increased the seedling dry weight over control (Table 3). Highest seedling dry weight (1.80 mg) was in seed primed withPEG 6000 -1.2 MPa for 4 days (P_4) and lowest seedling dry weight (1.69 mg) was in non-primed seed (P_5). Among the pelleted seed, the highest seedling dry weight (1.84 mg) was in PL_3*i.e. Melia azedarach* leaf powder pelleted seeds and lowest seedling dry weight (1.68 mg) was observed in PL_7*i.e.* unpelleted seed. Interaction effect showed that treatment combination of PEG 6000 -1.2 MPa for 4 days primed seed with *Melia azedarach* leaf powder seed (P_4 x PL_3) resulted in highest seedling dry weight (2.24 mg). However, the lowest seedling dry weight (1.52 mg) was in treatment combination P_5 x PL_7 *i.e.* control.

Activity of dehydrogenases (seed viability indicator) and peroxidises known as free radical scavenging enzyme had caused increased seedling dry weight in primed seeds (Nagarajan et al 2003). These findings are in line with that of Govinden-Soulange and Levantard (2008) in tomato, Sadeghi et al (2011) in Soybean, Dorna et al (2014) in pansy and Kumar et al (2017) in chick pea.Geetha and Balamurugan (2011) recorded increased seedling dry weight in mustard as a result of seed pelleting with leaf powder of *Propis julifora*. Ramesh and Muthukrishnan (2015) also observed similar trend in okra

Table 2. Effect of combined application of seed priming and pelleting on seedling length (cm) in carrot cv. early nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	15.56	15.86	15.36	12.40	16.90	15.22
*Eucalyptus*species + clay (PL_2)	16.42	14.54	15.20	15.28	15.34	15.36
Melia azedarach + clay (PL_3)	18.06	18.24	17.24	20.30	17.78	18.32
Vitex negundo + clay (PL_4)	13.70	14.90	19.36	16.94	14.42	15.86
Clay (PL_5)	16.48	17.34	16.42	16.50	13.94	16.14
Gum arabica (PL_6)	15.24	17.94	11.48	16.24	12.72	14.72
Control (Unpelleted) (PL_7)	11.13	14.66	16.40	19.22	11.40	14.56
Mean	15.23	16.21	15.92	16.70	14.64	
CD (p=0.05)						
P	0.2316					
PL	0.2740					
P x PL	0.6127					

Table 3. Effect of combined application of seed priming and pelleting on seedling dry weight (mg) in carrot cv. early nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	1.70	1.72	1.72	1.72	1.70	1.71
*Eucalyptus*species + clay (PL_2)	1.72	1.74	1.74	1.70	1.72	1.72
Melia azedarach + clay (PL_3)	1.74	1.76	1.72	2.24	1.74	1.84
Vitex negundo + clay (PL_4)	1.68	1.72	1.82	1.70	1.70	1.72
Clay (PL_5)	1.72	1.56	1.70	1.70	1.72	1.68
Gum arabica (PL_6)	1.74	1.68	1.74	1.74	1.72	1.72
Control (Unpelleted) (PL_7)	1.72	1.68	1.70	1.78	1.52	1.68
Mean	1.72	1.69	1.73	1.80	1.69	
CD (p=0.05)						
P	0.0176					
PL	0.0208					
P x PL	0.0466					

and chilli pepper seed pelleted with *Annona squamosa* leaf powder leading to an increase in seedling dry weight.

Seed vigour index- length: Priming and pelleting affected significantly seed vigour of carrot seeds. Maximum seed vigour index-length (1462.69) was in PEG 6000 -1.2 MPa for 4 days primed seed (P_4) followed by P_2 *i.e.* PEG 6000 -1.0 MPa for 4 days primed seed (1292.76) and the lowest (1133.02) seed vigour index-length was recorded in non-primed seed (P_5). Among the pelleting materials, PL_3 *i.e. Melia azedarach* leaf powder pelleting resulted into the highest seed vigour index-length (1626.25), where, the lowest (1138.65) seed vigour index-length was in PL_7*i.e.* unpelleted seed. Interaction effects revealed that combination P_4 x PL_3 *i.e.* PEG 6000 -1.2 MPa for 4 days primed seed and pelleted with *Melia azedarach* leaf powder pelleted seeds recorded the highest seed vigour index-length (1897.98). However, the lowest seed vigour index-length (736.16) was in control (P_5 x PL_7) (Table 4).

Seed vigour index- mass: The maximum seed vigour index- mass (156.97) was with PEG 6000 -1.2 MPa for 4 days primed seed (P_4) and the lowest (130.14) was in non-primed seed (P_5). Amongst the pelleting, PL_3 *i.e. Melia azedarach* leaf powder pelleted seeds resulted into the highest seed vigour index- mass (163.53), while, the lowest (129.55) was in unpelleted seed. Interaction effect due to priming and pelleting resulted that treatment combination P_4 x PL_3*i.e.* PEG 6000 -1.2 MPa for 4 days primed seed with *Melia azedarach* leaf powder pelleting recorded the highest seed vigour index- mass (209.46). However, the lowest seed vigour index- mass (100.33) was observed in combination P_5 x PL_7*i.e.* control (Table 5).

The increase in seed vigour is due to osmotic priming resulting in mobilization of the seed reserve, enzyme activation, enzyme re-synthesis, DNA and RNA replication (Sadeghi et al 2011). Priming has resulted in increased seed vigour index- mass in tomato Govinden-Soulange and Levantard (2008), in pansy (Dorna et al (2014), in chick pea Kumar et al (2017) and in Soybean Sadeghi et al (2011). Due to presence of micronutrients, saponins and gibberellic substances in the botanicals like *Melia azedarach*, *Azadirachta indica* leaf powders, increased seedling vigour has been reported (Vanangamudi et al 2010). Enhanced vigour has also been reported through seeds pelleted with various leaf powder in French bean (Babu et al 2005), in *Cenchrus* (Geetha and Krishnasamy 2011), in tomato (Shashibhasker et al 2011), in okra (Ramesh and Muthukrishnan 2015, in red gram (Anbarsan et al 2016), and black gram (Prakash et al 2018). Seed pelleting of red gram seed with botanical leaf powder has to increase seed germination and vigour (Anbarsan et al 2016).

Speed of germination: The speed of germination (24.61) with PEG 6000 -1.2 MPa for 4 days primed seed (P_4) was found maximum followed by PEG 6000 -1.2 MPa for 2 days primed seed (P_3) and the lowest speed of germination (22.27) was recorded in PEG 6000 -1.0 MPa for 2 days primed seed (P_2) (Table 6). Amongst the pelleting, PL_3 *i.e. Melia azedarach* leaf powder pelleted seeds resulted into the highest speed of germination (25.92), while the lowest speed of germination (20.23) was observed in PL_7*i.e.* unpelleted seed. Interaction effect revealed that combined treatment of P_4 x PL_6*i.e.* PEG 6000 -1.2 MPa for 4 days primed seed with Gum Arabica pelleting recorded the highest speed of germination (28.33).

Table 4. Effect of combined application of seed priming and pelleting on seedling vigour index-length (SVI-L) in carrot cv. early nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	1361.49	1268.79	1236.48	991.99	1318.18	1235.39
*Eucalyptus*species + clay (PL_2)	1428.82	1119.61	1185.77	1306.40	1296.20	1267.36
Melia azedarach + clay (PL_3)	1580.14	1623.04	1465.34	1897.98	1564.76	1626.25
Vitex negundo + clay (PL_4)	1089.22	1154.64	1791.02	1482.26	1103.05	1324.04
Clay (PL_5)	1372.73	1335.15	1222.83	1400.16	926.95	1251.56
Gum arabica (PL_6)	1302.99	1426.54	901.26	1420.96	985.81	1207.51
Control (Unpelleted) (PL_7)	858.22	1121.58	1238.20	1739.09	736.16	1138.65
Mean	1284.80	1292.76	1291.56	1462.69	1133.02	
CD (p=0.05)						
P	23.3937					
PL	27.6810					
P x PL	61.8965					

Table 5. Effect of combined application of seed priming and pelleting on seedling vigour index-mass (SVI-M) in carrot cv. early nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	148.75	137.63	138.45	137.60	132.61	139.01
*Eucalyptus*species + clay (PL_2)	149.55	133.97	135.71	145.35	145.33	141.98
Melia azedarach + clay (PL_3)	152.25	154.86	146.20	209.46	154.88	163.53
Vitex negundo + clay (PL_4)	133.53	133.28	168.31	148.78	130.10	142.80
Clay (PL_5)	143.28	120.12	126.65	144.21	114.41	129.74
Gum arabica (PL_6)	148.75	133.54	136.60	152.28	133.33	140.90
Control (Unpelleted) (PL_7)	129.47	128.53	128.35	161.09	100.33	129.55
Mean	143.65	134.56	140.04	156.97	130.14	
CD (p=0.05)						
P	2.1720					
PL	2.5699					
P x PL	5.7465					

Table 6. Effect of combined application of seed priming and pelleting on speed of germination in carrot cv. Early Nantes

Treatments	PEG 6000 -1.0 MPa for 2 days (P_1)	PEG 6000 -1.0 MPa for 4 days (P_2)	PEG 6000 -1.2 MPa for 2 days (P_3)	PEG 6000 -1.2 MPa for 4 days (P_4)	Control (Non primed) (P_5)	Mean
Lantana camara + clay (PL_1)	24.22	21.49	22.22	22.65	22.40	22.60
*Eucalyptus*species + clay (PL_2)	23.33	21.33	24.33	23.33	24.20	23.30
Melia azedarach + clay (PL_3)	27.22	26.22	26.65	27.22	22.30	25.92
Vitex negundo + clay (PL_4)	22.42	22.62	25.33	24.22	22.64	23.45
Clay (PL_5)	22.30	24.33	26.33	25.27	25.20	24.69
Gum arabica (PL_6)	23.93	20.53	23.20	28.33	23.10	23.82
Control (Unpelleted) (PL_7)	20.13	19.34	22.33	21.22	18.12	20.23
Mean	23.36	22.27	24.34	24.61	22.57	
CD (p=0.05)						
P	0.230					
PL	0.272					
P x PL	0.609					

However, the lowest speed of germination (18.12) was observed in combination P_5 x PL_7*i.e.* control.

Seed priming of dry seeds with PEG 6000 results in quick radical emergence, rapid and early germination due to completion of various metabolic activities (Arif 2005). The attributed reasons may be rapid imbibition and reduction of the inbuilt physiological heterogeneity and molecular attributes related to germination and enhanced peroxidase activities and increased rate of respiration and repair mechanisms linked with seed inhibition. These results are in line with the findings of Sadeghi et al (2011) in soybean. Pelleting with various leaf powder have also been reported to enhance seed germination in tomato (Shashibhasker et al 2011), in okra and chilli (Ramesh and Muthukrishnan 2015) and blackgram seed (Prakash et al 2018).

CONCLUSION

The carrot seed primed for 4 days in PEG 6000 solution having osmotic potential of -1.2 MPa was best among the various priming treatments and showed noticeable effects on germination and vigour of carrot seed over non-primed seed. For the majority of the germination and vigour characteristics among the pelleting treatments, seed pelleted with *Melia azedarach* leaf powder showed significantly higher values. Additionally, treatment combination ofcarrot seed primed for 4 days in PEG 6000 solution having osmotic potential of -1.2 MPa and pelleted with *Melia azedarach* leaf powder resulted higher values for germination and vigour which ultimately leads to the good crop stand under field condition and will ultimately help the farmers in achieving higher production and productivity.

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Studies on Pollination, Fruit Set and Self-Incompatibility Index in Apple Varieties under Wet Temperate Conditions of Himachal Pradesh

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Abstract: In the present study, floral biology, the extent of fruit set under different modes of pollination, the relationship between fruit shape and seed number, and the compatibility status among different apple varieties were studied. Fruit characters and yield are directly influenced by floral characteristics, flowering time, flowering duration and pollen fertility. Flowering duration varied from 10 days (Scarlet Spur II and Schlect Spur) to 15 days (Granny Smith). Pollen viability ranged from 72.43 per cent (Ace Spur) to 96.83 per cent (Coe Red Fuji) in 1 per cent acetocarmine solution, and from 76.21 per cent (Schlect Spur) to 90.85 per cent (Gale Gala) in 0.04 percent erythrosine B. The findings showed that, Gale Gala and Granny Smith were superior pollinizers. Seed number was maximum (9.40) under hand/controlled pollination and minimum (2.40) under bagging conditions. When the seed number was low, there was a higher percentage of lopsided fruits, and vice versa. All the main varieties were completely self-incompatible, whereas the pollinizing varieties were found to be partially as well as fully self-compatible. It was concluded that a cross compatible variety is required for optimum fruit set in apples, and that the number of seeds in fruit has a direct effect on its shape, size and weight.

Keywords: Floral Biology, Lopsidedness, *Malus* × *domestica* Borkh, Pollination, Self-incompatibility

The cultivated apple (*Malus* × *domestica* Borkh.) is a major commercial crop in temperate regions of the world. The total area under apple cultivation in India is 3,15,000 hectares with a production of 25,89,000 metric tonnes, whereas, in Himachal Pradesh the area is 1,15,020 hectares with a production of 6,11,900 metric tonnes (Anonymous 2022). In apple, the pollinizing ability of any variety is determined by its floral characteristics, duration of flowering, fertility and germination of pollen grains. The low productivity of apples might be due to a variety of factors including climate, soil characters, the occurrence of pests and diseases, a lack of pollination and a lack of synchronization among the flowering periods.

In apples, cross pollination is a very important aspect for quality fruit production since it contains a complex biochemical mechanism that prevents the ovules from being fertilized by its own pollen (Hua et al 2008). This gametophytic incompatibility mechanism is genetically controlled by a single locus, i.e., the S-locus, which includes at least two polymorphic and strongly linked S-determinant genes: a pistil-expressed *S-RNase* gene and a number of pollen-expressed *SFBB* genes i.e., S-locus F-Box Brothers (Claessen et al 2019). The self or non-self-recognition process and the acceptance or rejection takes place between the protein products of these genes. The varieties with the same S-genotype are mutually incompatible because self S-RNase can stop the pollen tube expansion, resulting in fertilisation failure, and so their mating will not result in a progeny. Due to this self-incompatibility mechanism, in apples, majority of cultivars exhibit a higher level of allelic heterozygosity, are thus not true to type and ultimately result in fruits of poor size, shape and quality (Webster and Wertheim 2003). Furthermore, the number and distribution of seeds are also important in producing marketable apples with better size and shape. The hormones that are produced by developing seeds influence the growth in the tissues, which ultimately leads to better shape and size of the fruit (Sheffield 2014).

The lack of pollination leads to very less or no fertilization, thus producing lopsided and unmarketable fruits. For these reasons, it has become evident that there is an urgent need for the identification of suitable pollinizing cultivars to counter the problem of inadequate pollination, which ultimately leads to inferior quality and poor yield. Furthermore, knowledge about the floral behaviour of different varieties of apples might be important in relation to different climatic conditions for breeding new varieties suitable for different climatic conditions. So far, very limited data is available with respect

to pollen viability and *in-vitro* pollen germination in the varieties undertaken for the present study. Furthermore, the viability and germination of a wide range of varieties across a wide range of environmental conditions also remain to be investigated. The objective of study was to identify variety with better pollinizing abilities to resist the problem of low productivity in apples.

MATERIAL AND METHODS

The present investigations were carried out during the years 2020 and 2021 at the Regional Horticultural Research and Training Station, Mashobra, Shimla (elevation: 2286 m above mean sea level; latitude 31.1°N; and longitude 77.1°E). The six commercial varieties *viz*. Scarlet Spur II, Oregon Spur II, Early Red One, Super Chief, Ace Spur and Schlect Spur along with four pollinizing varieties *viz*. Gale Gala, Granny Smith, Coe Red Fuji and Crimson Gala were taken. Flower length, breadth, length of sepals, petals, pistil and ovary diameter were measured. The colour of sepals, petals, anthers and the flower at balloon stage were recorded using colour chart of Royal Horticultural Society, London. The date on which 5-10 per cent flowers had opened was recorded as the date of initiation of flowering, whereas the date on which about 75 per cent flowers had opened was recorded as the date of full bloom. The date on which the last flower opened in each variety was recorded as the time of opening of last flower and the number of days from date of initiation of flowering to the date of opening of last flower in each variety was recorded as the duration of flowering. Pollen viability was observed in 1 per cent acetocarmine solution and 0.04 per cent erythrosine B solutions and *in vitro* pollen germination was observed in 10 per cent sucrose + 0.5 per cent agar solutions.

To investigate fruit characteristics, a total of 15 representative fruit samples were carefully selected at their peak ripeness. These samples were divided into three sets, with each set containing five fruit replicates. For precise measurements of fruit dimensions, a Digital Vernier Calipers (Model No. CD-6" CS) was employed to record the length and breadth of each fruit in millimeters (mm). Furthermore, a visual inspection of the fruits was conducted to categorize them as either symmetrical or asymmetrical based on their overall shape and appearance. The weight of the fruits resulting from various pollination methods was determined. To assess the fruit's physical characteristics more comprehensively, each fruit was cut in half lengthwise. The depth of the fruit basin was then measured using a measuring scale and categorized as either shallow, medium, or deep based on the depth observed. Seed number in each fruit was assessed by slicing the apples horizontally through the equatorial plane and counting the number of fully developed seeds. The self-incompatibility index was calculated with the values of seed set obtained in self-pollination and cross pollination treatments (Moriya et al 2005). The values of self-incompatibility index range from 0 to 1, where 0 indicates complete self-incompatibility and 1 indicates a fully self-compatible species. A self-incompatibility index of > 0.75 clearly differentiates between fully and partially self-compatible species, whereas an index of < 0.20 is related to fully incompatible species (Castro et al 2016). The cross-compatibility of a particular cross combination was established according to Maliga (1953), cited by Nyeki (1996).

a, b, c, d and e cultivars that can fertilize another to a

a. negligible extent (fruit set ≥0% and <2%)
b. slight extent (fruit set ≥2% and <10%)
c. medium extent (fruit set ≥10% and<20%)
d. high extent (fruit set ≥20% and <30%)
e. large extent (fruit set ≥30%).

RESULTS AND DISCUSSION

Floral biology: The average flower length and breadth were at 38.60 mm and 34.87 mm (Table 1). Majid (2003) also observed variations in flower diameter from 3.6 cm to 5.3 cm. Pandit (2014) recorded flower diameter in the range of 4.00 cm to 5.30 cm. The number of sepals and petals was five in all the varieties under study. The maximum (19.50) number of stamens in all varieties was in Granny Smith and minimum (17.00) in Scarlet Spur II. However, Dennis (2003) reported stamen numbers varying from 20 to 25 among different apple varieties. Pistil length varied from 10.70 mm (Early Red One) to 15.57 mm (Super Chief). Sepal length was maximum (7.66 mm) in Early Red One and minimum (5.99 mm) in Coe Red Fuji. However, the maximum petal length (23.15 mm) was in Super Chief and minimum (14.95 mm) in Ace Spur. Maximum (2.63 mm) ovary diameter was in Oregon Spur II which was statistically at par with Super Chief, Schlect Spur and Crimson Gala and minimum (2.08 mm) in Coe Red Fuji. Anand (2003) observed variations in sepal and pistil lengths from 0.55 - 0.82 cm and 0.63 - 1.36 cm, respectively. Chauhan (2018) also observed variation in pistil length from 0.69 cm to 0.91 cm. These variations in floral parameters might be due to varietal differences (Monteiro et al 2015, Dangi et al 2021).

The flower initiation was earliest in Crimson Gala (26th March), however, Schlect Spur was the last to initiate flowering i.e. on 12th April. Full bloom was earliest in Crimson Gala (31st March) and Schlect Spur was the last to come into full bloom on 16th April. The date of opening of last flower varied from 9th April to 22ndApril, Crimson Gala and Ace Spur being the earliest and Schlect Spur being the last. Earliest

Table 1. Floral characters of different apple varieties

Variety	Flower length (mm)	Flower breadth (mm)	Arrangement of petals	Colour of sepals	Colour of petals	Colour of anthers	Colour of flowers at balloon stage	Number of sepals	Number of petals	Number of stamens	Length of sepal (mm)	Length of petal (mm)	Length of pistil (mm)	Ovary diameter (mm)
Scarlet Spur-II	36.19	33.36	Touching	Green group 139 B	White group 155 B	Yellow group 5 C	Red-Purple group 58 D	5	5	17 (15-19)	6.33	17.21	12.16	2.33
Oregon Spur II	40.46	35.74	Touching	Yellow-Green group 144 B	White group N 155 D	Yellow group 10 D	Red-Purple group 64 C	5	5	18.5 (17-20)	6.73	17.45	11.25	2.63
Early Red One	40.47	36.70	Touching	Yellow-Green group 144 B	Red-Purple group N 74 D	Yellow group 8 C	Red-Purple group 58 C	5	5	17.3 (16-20)	7.66	19.67	10.70	2.21
Super Chief	46.41	39.59	Touching	Green group 138 C	White group N 155 C	Yellow group 10 C	Red-Purple group 59 D	5	5	18 (15-20)	6.24	23.15	15.57	2.45
Ace Spur	35.29	32.91	Touching	Green group 139 D	White group 155 B	Yellow group 4 C	Red-Purple group N 66 C	5	5	18.7 (16-20)	7.27	14.95	10.84	2.25
Schlect Spur	35.88	32.41	Touching	Yellow-Green group 144 B	White group 155 B	Yellow group 5 D	Red-Purple group 64 C	5	5	18.8 (17-20)	7.54	21.06	12.47	2.38
Gale Gala	36.69	34.28	Apart	Green group 139 D	Red-Purple group N 66 C	Greyed-Yellow group 162 D	Red-Purple group 63 B	5	5	18.3 (17-20)	7.18	18.32	13.49	2.17
Granny Smith	43.44	40.84	Touching	Green group 139 D	White group N 155 B	Greyed Orange group 165 B	Red-Purple group 60 A	5	5	19.5 (19-20)	6.60	21.75	15.35	2.33
Coe Red Fuji	36.37	31.02	Apart	Green group 139 D	White group N 155 D	Yellow group 5 D	White group 155 C	5	5	18.3 (17-20)	5.99	15.68	14.25	2.08
Crimson Gala	34.79	31.82	Apart	Green group 139 D	Greyed-Purple group 186 C	Yellow group 2 C	Red-Purple group 58 B	5	5	18.5 (17-20)	7.61	16.76	12.65	2.55
Mean	38.60	34.87						5	5	18.29	6.92	18.60	12.87	2.34
CD at 5 %	0.02	0.03									0.34	0.61	0.38	0.25

petal fall was observed in varieties Crimson Gala and Ace Spur (13th April), however, the last variety to show petal fall was Schlect Spur (25th April). These differences in dates of flowering might be due to their genetic characteristics or their responses to light and prevailing temperature. The longest flowering duration (15 days) was in Granny Smith, whereas, the shortest duration (10 days) was observed in Scarlet Spur II and Schlect Spur (Table 2, Fig. 1). Singh et al (2002) observed flowering duration to vary between 10 and 15 days among different apple cultivars. Sharma et al (2017) reported duration of flowering to vary from 12 to 16 days. The longest (20 days) duration of flowering was observed in Granny Smith and shortest (11 days) in Scarlet Spur II (Verma and Thakur 2019). These variations in time and duration of flowering might be due to differences in cultural practices, environmental conditions and chilling requirements (Dangi et al 2024) of different apple cultivars, which help in breaking bud dormancy and regulating flowering.

Pollen viability and *in vitro* pollen germination: In 1 per cent acetocarmine solution, Coe Red Fuji showed the highest pollen viability (96.83%) and Ace Spur the lowest (72.43%). However, in 0.04 per cent erythrosine B, pollen viability varied from 76.21 per cent (Schlect Spur) to 90.85 per cent (Gale Gala) (Table 2). The observed variations in pollen viability percentage might be due to the prevailing climatic conditions, which may affect the physiology of the pollen grains (Singh et al 2002). Rather et al (2018) observed pollen viability in 1 per cent acetocarmine solution ranged from 64.50 to 100.00 per cent, with Granny Smith achieving 97.94 per cent and Coe Red Fuji achieving 97.53 per cent.

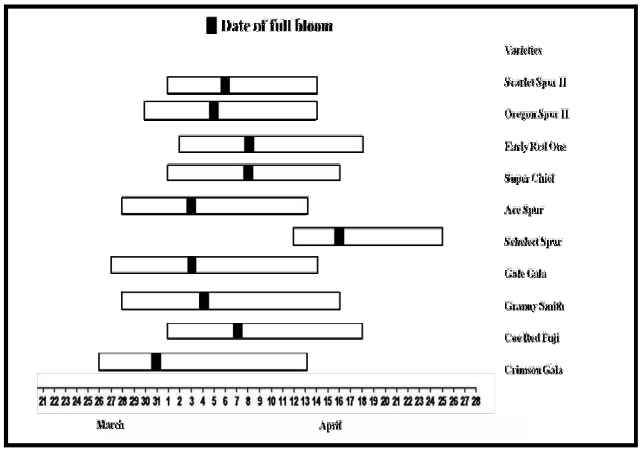

Fig. 1. Time and duration of flowering in different apple varieties (from initiation of flowering to petal fall)

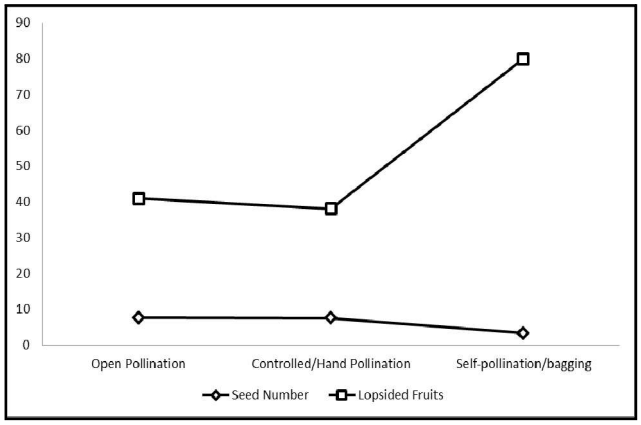

Fig. 2. Relationship between seed number and degree of lopsidedness under different modes of pollination

Table 2. Time, duration of flowering, pollen viability and *in vitro* germination of different apple varieties

Variety	Time of initiation of flowering	Time of full bloom	Time of opening of last flower	Total duration of flowering (days)	Time of petal fall	Pollen viability (%)		*In vitro* pollen germination in 10 % sucrose + 0.5 % agar (%)
						Acetocarmine (1%)*	Erythrosine B (0.04%)*	
Scarlet Spur II	01st April	06th April	11th April	10	14th April	82.03 (9.11)	80.53 (9.03)	39.82
Oregon Spur II	30th March	05th April	10th April	11	14th April	80.37 (9.02)	80.42 (9.02)	40.27
Early Red One	02nd April	08th April	14th April	12	18th April	79.36 (8.96)	77.18 (8.84)	42.51
Super Chief	01st April	08th April	13th April	12	16th April	77.78 (8.88)	78.67 (8.93)	39.24
Ace Spur	28th March	03rd April	09th April	12	13th April	72.43 (8.57)	77.41 (8.86)	44.29
Schlect Spur	12th April	16th April	22nd April	10	25th April	74.52 (8.69)	76.21 (8.79)	45.70
Gale Gala	27th March	03rd April	10th April	14	14th April	95.96 (9.85)	90.85 (9.58)	59.74
Granny Smith	28th March	04th April	12th April	15	16th April	95.66 (9.83)	88.25 (9.45)	64.94
Coe Red Fuji	01st April	07th April	14th April	13	18th April	96.83 (9.89)	88.97 (9.46)	62.29
Crimson Gala	26th March	31st March	09th April	14	13th April	89.40 (9.51)	90.05 (9.54)	57.01
Mean						84.43 (9.23)	82.86 (9.15)	49.58
CD (P=0.05)						(0.05)	(0.18)	02.67

*Figure in parenthesis is square root (*) transformed

Table 3. Pollination treatments applied to main apple varieties under study, fruit set, retention, number of seeds/fruit, SI index and compatibility status

Treatment	Female variety	Male variety	Fruit set (%)	Fruit retention (%)	Number of seeds/fruit	Degree of lopsidedness (%)*	SI Index	Compatibility status
Scarlet Spur II								
Open Pollination	Scarlet Spur II	-	85.28	45.45	7.32	40.00 (39.22)	-	-
Self-pollination/Bagging	Scarlet Spur II	Scarlet Spur II	12.66	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Scarlet Spur II	Gale Gala	36.42	66.66	9.00	13.33 (21.39)	-	Cross-compatible to a large extent
Cross pollination	Scarlet Spur II	Granny Smith	65.75	62.50	7.60	33.33 (35.25)	-	Cross-compatible to a large extent
Cross pollination	Scarlet Spur II	Coe Red Fuji	51.88	37.50	8.00	26.67 (31.08)	-	Cross-compatible to a large extent
Cross pollination	Scarlet Spur II	Crimson Gala	21.71	21.67	6.20	46.67 (43.07)	-	Cross-compatible to a high extent
Oregon Spur II								
Open Pollination	Oregon Spur II	-	59.69	69.23	8.10	26.67 (31.08)	-	-
Self-pollination/Bagging	Oregon Spur II	Oregon Spur II	4.91	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Oregon Spur II	Gale Gala	0.00	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a negligible extent
Cross pollination	Oregon Spur II	Granny Smith	15.25	100.00	7.33	40.00 (39.21)	-	Cross-compatible to a medium extent
Cross pollination	Oregon Spur II	Coe Red Fuji	0.00	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a negligible extent
Cross pollination	Oregon Spur II	Crimson Gala	4.69	100.00	9.00	13.33 (21.39)	-	Cross-compatible to a slight extent
Early Red One								
Open Pollination	Early Red One	-	75.16	78.95	7.68	40.00 (39.22)	-	-
Self-pollination/Bagging	Early Red One	Early Red One	5.89	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Early Red One	Gale Gala	10.78	100.00	8.00	33.33 (35.25)	-	Cross-compatible to a medium extent
Cross pollination	Early Red One	Granny Smith	25.14	66.67	9.00	13.33 (21.39)	-	Cross-compatible to a high extent
Cross pollination	Early Red One	Coe Red Fuji	26.78	20.00	8.00	26.67 (31.08)	-	Cross-compatible to a high extent
Cross pollination	Early Red One	Crimson Gala	51.76	50.00	8.00	26.67 (31.08)	-	Cross-compatible to a large extent
Super Chief								
Open Pollination	Super Chief	-	78.14	74.19	7.25	40.00 (39.22)	-	-
Self-pollination/Bagging	Super Chief	Super Chief	7.53	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Super Chief	Gale Gala	57.58	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a large extent
Cross pollination	Super Chief	Granny Smith	11.43	50.00	6.00	53.33 (46.89)	-	Cross-compatible to a medium extent
Cross pollination	Super Chief	Coe Red Fuji	66.88	11.11	6.00	53.33 (46.89)	-	Cross-compatible to a large extent
Cross pollination	Super Chief	Crimson Gala	13.54	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a medium extent
Ace Spur								
Open Pollination	Ace Spur	-	55.61	85.71	6.48	53.33 (46.89)	-	-
Self-pollination/Bagging	Ace Spur	Ace Spur	15.99	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Ace Spur	Gale Gala	18.57	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a medium extent
Cross pollination	Ace Spur	Granny Smith	28.45	66.67	6.30	46.67 (43.07)	-	Cross-compatible to a high extent
Cross pollination	Ace Spur	Coe Red Fuji	28.54	50.00	6.50	40.00 (39.21)	-	Cross-compatible to a high extent
Cross pollination	Ace Spur	Crimson Gala	60.82	14.29	8.00	26.67 (31.08)	-	Cross-compatible to a large extent
Schlect Spur								
Open Pollination	Schlect Spur	-	56.13	33.33	7.70	26.67 (31.08)	-	-
Self-pollination/Bagging	Schlect Spur	Schlect Spur	2.75	0.00	0.00	0.00 (0.00)	0.00	Complete self-incompatible
Cross pollination	Schlect Spur	Gale Gala	100.00	50.00	7.00	33.33 (35.25)	-	Cross-compatible to a large extent
Cross pollination	Schlect Spur	Granny Smith	54.94	25.00	9.00	13.33 (21.39)	-	Cross-compatible to a large extent
Cross pollination	Schlect Spur	Coe Red Fuji	57.30	0.00	0.00	0.00 (0.00)	-	Cross-compatible to a large extent
Cross pollination	Schlect Spur	Crimson Gala	62.59	50.00	8.00	13.33 (21.39)	-	Cross-compatible to a large extent

*Figure in parenthesis is angular (*) transformed

Table 4. Pollination treatments applied to different pollinizing apple varieties under study, fruit set, retention, number of seeds/fruit, SI index and compatibility status

Treatment	Female variety	Male variety	Fruit set (%)	Fruit retention (%)	Number of seeds/fruit	Degree of lopsidedness (%)*	SI Index	Compatibility status
Gale Gala								
Open Pollination	Gale Gala	-	70.80	72.13	8.32	20.00 (26.55)	-	-
Self-pollination/bagging	Gale Gala	Gale Gala	22.00	75.00	3.00	80.00 (63.41)	0.38	Partially self-compatible
Cross pollination	Gale Gala	Scarlet Spur II	30.86	100.00	7.33	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Oregon Spur II	48.43	100.00	6.80	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Early Red One	12.14	100.00	9.00	6.67 (14.90)	-	Cross compatible to a medium extent
Cross pollination	Gale Gala	Super Chief	50.27	40.00	6.30	46.67 (43.07)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Ace Spur	27.09	50.00	6.40	46.67 (43.07)	-	Cross compatible to a high extent
Cross pollination	Gale Gala	Schlect Spur	36.46	40.00	7.33	33.33 (35.25)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Granny Smith	46.78	90.00	9.00	13.33 (21.39)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Coe Red Fuji	31.56	80.00	9.40	6.67 (14.90)	-	Cross compatible to a large extent
Cross pollination	Gale Gala	Crimson Gala	27.85	16.67	9.00	20.00 (26.54)	-	Cross compatible to a high extent
Granny Smith								
Open Pollination	Granny Smith	-	80.53	50.00	7.72	26.67 (31.08)	-	-
Self-pollination/bagging	Granny Smith	Granny Smith	27.84	40.00	4.50	66.67 (54.72)	0.87	Fully self-compatible
Cross pollination	Granny Smith	Scarlet Spur II	51.91	0.00	0.00	0.00 (0.00)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Oregon Spur II	59.70	0.00	0.00	0.00 (0.00)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Early Red One	45.95	50.00	7.23	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Super Chief	50.53	100.00	6.80	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Ace Spur	33.69	50.00	9.00	6.67 (14.90)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Schlect Spur	45.40	0.00	0.00	0.00 (0.00)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Gale Gala	64.76	55.45	8.25	20.00 (26.54)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Coe Red Fuji	70.42	55.56	7.50	26.67 (31.08)	-	Cross compatible to a large extent
Cross pollination	Granny Smith	Crimson Gala	23.61	50.00	8.00	26.67 (31.08)	-	Cross compatible to a high extent
Coe Red Fuji								
Open Pollination	Coe Red Fuji	-	91.56	77.77	7.85	33.33 (35.25)	-	-
Self-pollination/bagging	Coe Red Fuji	Coe Red Fuji	50.07	66.67	3.20	73.33 (58.88)	0.46	Partially self-compatible
Cross pollination	Coe Red Fuji	Scarlet Spur II	50.10	100.00	6.40	46.67 (43.07)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Oregon Spur II	75.85	66.67	6.50	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Early Red One	49.96	100.00	6.40	46.67 (43.07)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Super Chief	66.86	20.00	7.00	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Ace Spur	28.79	50.00	6.50	40.00 (39.21)	-	Cross compatible to a high extent
Cross pollination	Coe Red Fuji	Schlect Spur	47.59	83.33	6.60	33.33 (35.25)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Gale Gala	52.57	75.00	8.60	20.00 (26.54)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Granny Smith	36.39	85.71	8.75	26.67 (31.08)	-	Cross compatible to a large extent
Cross pollination	Coe Red Fuji	Crimson Gala	23.94	33.33	6.50	40.00 (39.21)	-	Cross compatible to a high extent
Crimson Gala								
Open Pollination	Crimson Gala	-	77.60	85.29	8.00	26.67 (31.08)	-	-

Cont...

Table 4. Pollination treatments applied to different pollinizing apple varieties under study, fruit set, retention, number of seeds/fruit, SI index and compatibility status

Treatment	Female variety	Male variety	Fruit set (%)	Fruit retention (%)	Number of seeds/fruit	Degree of lopsidedness (%)*	SI Index	Compatibility status
Self-pollination/bagging	Crimson Gala	Crimson Gala	21.79	75.00	2.40	86.67 (68.56)	0.41	Partially self-compatible
Cross pollination	Crimson Gala	Scarlet Spur II	56.16	0.00	0.00	0.00 (0.00)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Oregon Spur II	41.64	75.00	6.60	40.00 (39.21)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Early Red One	45.86	12.50	8.00	20.0 (26.54)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Super Chief	47.58	42.86	6.80	46.67 (43.07)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Ace Spur	26.83	33.33	8.00	20.00 (26.54)	-	Cross compatible to a high extent
Cross pollination	Crimson Gala	Schlect Spur	64.41	33.33	8.00	20.00 (26.54)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Gale Gala	41.56	0.00	0.00	0.00 (0.00)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Granny Smith	30.70	71.43	8.80	13.33 (21.39)	-	Cross compatible to a large extent
Cross pollination	Crimson Gala	Coe Red Fuji	67.12	47.12	7.00	33.33 (35.25)	-	Cross compatible to a large extent

*Figure in parenthesis is angular (*) transformed

Table 5. Effect of open pollination and bagging on fruit characters of different apple varieties

Variety	Under open pollination condition				Under bagging condition			
	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Depth of basin (cm)	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Depth of basin (cm)
Scarlet Spur II	59.61	65.51	122.37	0.80	0.00	0.00	0.00	0.00
Oregon Spur II	59.59	66.56	124.71	1.00	0.00	0.00	0.00	0.00
Early Red One	60.57	65.43	125.67	0.80	0.00	0.00	0.00	0.00
Super Chief	64.66	68.39	155.45	0.90	0.00	0.00	0.00	0.00
Ace Spur	58.71	58.47	104.11	0.60	0.00	0.00	0.00	0.00
Schlect Spur	66.28	73.37	135.55	1.10	0.00	0.00	0.00	0.00
Gale Gala	63.55	71.31	163.55	0.90	52.58	56.20	98.63	0.60
Granny Smith	64.66	72.59	162.42	0.70	64.24	76.20	154.61	0.60
Coe Red Fuji	57.39	67.23	131.69	0.50	59.44	66.91	130.56	0.30
Crimson Gala	55.37	63.17	139.92	0.60	39.21	61.73	68.73	0.50
Mean	61.04	67.20	136.54	0.79	53.87	65.26	113.13	0.50
CD (p=0.05)	0.48	0.52	0.36	0.001	0.05	1.02	0.57	0.10

Singh et al (2002) observed that pollen viability in 0.04 per cent erythrosine B ranged from 70.70 per cent to 90.32 per cent. *In vitro* pollen germination in 10 per cent sucrose + 0.5 per cent agar was found to range between 39.24 per cent and 64.94 per cent with maximum in Granny Smith and minimum in Super Chief. These variations in pollen germination might be due to the genetic constitution of pollen producing varieties, which influences the hormone level and its distribution which ultimately affects the physiology of pollen grains and thereby cause variations in viability and germination percentage (Kotiyal and Dimri 2017). In agreement with our present findings, Javid (2015) also observed that *in vitro* pollen germination ranged from 49.75 per cent (Manchurian) to 63.00 per cent (*Malus floribunda)*. However, Rather et al (2018) and Ahad et al (2020) reported *in vitro* pollen germination ranging between 44.24 per cent (Oregon Spur) and 64.54 per cent (Granny Smith) in 15 per cent sucrose solution. Higher values of pollen viability and germination in different apple varieties may be attributed to pollen fertility as a result of regular meiosis and the activation of certain enzyme systems present in the pollen itself (Nautiyal and Dimri 2009). Furthermore, viable pollen grains contain higher levels of pigments and free amino acids than non-viable pollens.

Fruit quality: The controlled or hand pollination resulted in the highest fruit length (69.53 mm), breadth (79.71 mm), and weight (196.58 g), followed by open pollination (Table 5, 6). The lowest fruit length, breadth, and weight (39.21 mm, 56.20

Table 6. Effect of controlled/hand pollination on fruit characters of different apple varieties

Cross combinations	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Depth of eye basin (cm)
Scarlet Spur II × Gale Gala	69.53	78.38	194.89	1.28
Gale Gala × Scarlet Spur II	54.84	63.95	100.78	1.30
Scarlet Spur II × Granny Smith	54.59	63.37	103.17	1.44
Granny Smith × Scarlet Spur II	0.00	0.00	0.00	0.00
Scarlet Spur II × Coe Red Fuji	47.71	72.04	129.51	1.17
Coe Red Fuji × Scarlet Spur II	52.22	63.84	103.67	1.28
Scarlet Spur II × Crimson Gala	49.52	66.10	104.22	1.30
Crimson Gala × Scarlet Spur II	0.00	0.00	0.00	0.00
Oregon Spur II × Gale Gala	0.00	0.00	0.00	0.00
Gale Gala × Oregon Spur II	52.97	64.11	100.98	1.10
Oregon Spur II × Granny Smith	57.65	70.04	140.42	1.27
Granny Smith × Oregon Spur II	0.00	0.00	0.00	0.00
Oregon Spur II × Coe Red Fuji	0.00	0.00	0.00	0.00
Coe Red Fuji × Oregon Spur II	50.55	63.41	99.75	1.16
Oregon Spur II × Crimson Gala	56.03	64.73	108.70	1.20
Crimson Gala × Oregon Spur II	40.24	56.96	79.59	1.35
Early Red One × Gale Gala	44.46	62.15	98.66	1.50
Gale Gala × Early Red One	59.35	69.96	149.64	1.40
Early Red One × Granny Smith	55.44	70.31	151.85	1.35
Granny Smith × Early Red One	54.34	65.59	106.42	1.00
Early Red One × Coe Red Fuji	51.33	60.48	94.71	1.20
Coe Red Fuji × Early Red One	56.70	67.78	120.80	1.30
Early Red One × Crimson Gala	48.38	60.20	90.53	1.28
Crimson Gala × Early Red One	45.51	60.38	84.92	1.10
Super Chief × Gale Gala	0.00	0.00	0.00	0.00
Gale Gala × Super Chief	39.58	61.42	88.06	1.30
Super Chief × Granny Smith	39.84	69.61	83.21	1.10
Granny Smith × Super Chief	62.76	71.13	142.33	1.74
Super Chief × Coe Red Fuji	39.98	60.11	71.63	1.30
Coe Red Fuji × Super Chief	54.51	66.81	115.32	1.50
Super Chief × Crimson Gala	0.00	0.00	0.00	0.00
Crimson Gala × Super Chief	52.33	62.08	98.43	1.10
Ace Spur × Gale Gala	0.00	0.00	0.00	0.00
Gale Gala × Ace Spur	56.50	62.52	132.88	1.10
Ace Spur × Granny Smith	45.65	57.67	82.63	1.60
Granny Smith × Ace Spur	59.99	71.50	145.05	1.80
Ace Spur × Coe Red Fuji	47.81	64.28	114.64	1.10
Coe Red Fuji × Ace Spur	58.47	70.48	136.48	1.30
Ace Spur × Crimson Gala	56.81	62.60	100.07	1.00
Crimson Gala × Ace Spur	48.19	62.28	82.05	1.10
Schlect Spur × Gale Gala	60.85	75.55	146.09	1.30
Gale Gala × Schlect Spur	54.91	68.24	114.15	1.67
Schlect Spur × Granny Smith	62.16	69.77	139.36	1.30

Cont...

Table 6. Effect of controlled/hand pollination on fruit characters of different apple varieties

Cross combinations	Fruit length (mm)	Fruit breadth (mm)	Fruit weight (g)	Depth of eye basin (cm)
Granny Smith × Schlect Spur	0.00	0.00	0.00	0.00
Schlect Spur × Coe Red Fuji	0.00	0.00	0.00	0.00
Coe Red Fuji × Schlect Spur	55.65	56.90	128.60	1.34
Schlect Spur × Crimson Gala	58.63	65.96	113.43	1.50
Crimson Gala × Schlect Spur	45.14	58.92	74.62	1.05
Gale Gala × Granny Smith	59.49	68.84	137.90	1.50
Granny Smith × Gale Gala	63.39	72.16	156.24	1.40
Gale Gala × Coe Red Fuji	69.16	79.71	196.58	1.02
Coe Red Fuji × Gale Gala	53.65	68.56	118.75	1.43
Gale Gala × Crimson Gala	65.42	78.26	196.50	1.40
Crimson Gala × Gale Gala	0.00	0.00	0.00	0.00
Granny Smith × Coe Red Fuji	59.95	70.57	139.68	1.78
Coe Red Fuji × Granny Smith	53.84	65.12	132.27	1.33
Granny Smith × Crimson Gala	64.57	74.24	163.74	1.35
Crimson Gala × Granny Smith	53.56	66.73	115.81	1.20
Coe Red Fuji × Crimson Gala	57.71	75.84	136.08	1.50
Crimson Gala × Coe Red Fuji	46.41	63.72	101.70	1.05
Mean	54.05	66.62	119.74	1.31
CD (p=0.05)	0.13	0.12	0.28	0.001

mm, and 68.73 g, respectively) were observed when bagging was used as the pollination method. These variations might be attributed to both the specific characteristics of the fruit variety studied and the distribution of seeds within the fruits. Dantas et al. (2001) and Chauhan (2018) also reported larger fruit sizes resulting from cross-pollination compared to open pollination. These variations in fruit size are not solely linked to pollination methods but can also be influenced by a combination of genetic and environmental factors. These factors include soil fertility, irrigation practices, nutrient levels, and various agricultural activities, all of which play a significant role in shaping the physical characteristics of the fruit.

Seed number and degree of lopsidedness: Under open pollination conditions, the percentage of asymmetrical fruits (degree of lopsidedness) ranged from 20.00 per cent in Gale Gala to 53.33 per cent in Ace Spur. The average seed number was 7.64, ranging from 6.48 (Ace Spur) to 8.32 (Gale Gala) (Table 3, 4). Under controlled pollination conditions, degree of lopsidedness was maximum (53.33 %) in Super Chief × Granny Smith and Super Chief × Coe Red Fuji and minimum (6.67%) in Gale Gala × Coe Red Fuji, Gale Gala × Early Red One and Granny Smith × Ace Spur. Maximum (9.40) number of seeds was observed in Gale Gala × Coe Red Fuji and minimum (6.00) in Super Chief × Granny Smith and Super Chief × Coe Red Fuji. Under bagging conditions, the percentage of asymmetrical fruits was highest (86.67%) in Crimson Gala and lowest (66.67%) in Granny Smith. The seed number was highest (9.40) under hand/controlled pollination and lowest (2.40) under bagging conditions. The percentage of lopsided fruits was substantially associated with seed quantity. The percentage of lopsided fruits was highest (86.67%) under bagging conditions and lowest (6.67%) under controlled/hand pollination conditions (Fig. 2). There was association between the number of seeds and the proportion of lopsided fruits, i.e., with the percentage of lopsided fruits being higher, the number of seeds was observed to be lower. Buccheri and Vaio (2004) and Sheffield (2014) observed that when the quantity of seeds increased, the percentage of deformed fruits decreased. According to Alabadi et al. (2009) and Balaguera-Lopez et al. (2020) synchronous activity of auxin and gibberellins hormones regulates the development of ovary into fruits. The hormones that are synthesized in seeds (auxins, gibberellins, brassinosteroids, cytokinins, polyamines, ethylene etc.) govern seed development and improve the activity of fruits to act as a sink, and ultimately result in a more uniform shape and better size of the fruit (Sun et al. 2010 and Kang et al. 2013).

Self-incompatibility index: The delicious group of varieties *viz.* Scarlet Spur II, Oregon Spur II, Early Red One, Super Chief, Ace Spur and Schlect Spur were completely self-

incompatible followed by Gale Gala, Coe Red Fuji and Crimson Gala which were partially self-compatible, whereas, Granny Smith was completely self-compatible (Tables 3, 4). The cross compatibility of the main varieties varied from being compatible to a negligible extent to being compatible to a large extent, whereas, all the pollinizing varieties were compatible to a higher or larger extent. This indicated the need for a pollinizing variety for optimum fruit set in the case of the delicious group of apple varieties.

CONCLUSION

The current study determined the degree of synchronization of flowering periods among different apple varieties, as well as the extent of fertility of pollen produced by them. All the pollinizing varieties were good source of pollen for the commercial varieties. However, among the pollinizing varieties under study, Gale Gala and Granny Smith were observed to be the best pollinizers, since their duration of flowering was in synchronization with most of the commercial varieties and their pollen viability and *in vitro* pollen germination were considerably higher. The shape of harvested fruits was influenced by the number of seeds present in the fruit. When the seed number was lower, a higher percentage of asymmetrical fruits were obtained. The present study also confirms the self-incompatible nature of delicious varieties of apple and highlights the importance of presence of a suitable pollinizing variety. From the cross pollination experiments, Gale Gala was administered as the best pollinizer, because when used as a source of pollen grains, gave maximum fruit set as compared to other pollinizing varieties.

AUTHORS CONTRIBUTION

Nikhil Kaushal, Girish Dangi and Akriti Chauhan - Designing of the experiments, execution of field/lab experiments, data collection, analysis of data, interpretation and preparation of manuscript; Dinesh S Thakur- Conceptualization and designing of the experiments; Neena Chauhan and RK Dogra -Assisted in the morphological and morphometric work.

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Impact of Vermicomposting with Soil Enriched with Plastic and Different Biodegradable Wastes on Physical, Chemical, and Biological Parameters of Soil

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***Abstract*:** The present work is a comparative study to understand the impact of various biodegradable wastes (hair, flower, vegetable peel, and spent coffee) and plastic on the soil quality. The biological parameters like the growth rate of worms, biomass gain, and cocoon production rate augmented considerably in soil enriched with all biodegradable waste groups when compared with soil contaminated with plastic. The health parameters of soil like pH, temperature, moisture content, exchangeable acidity, total organic carbon, nitrogen, phosphorus, and potassium (NPK) content significantly increased in soil enriched with vermicompost produced from coffee and vegetable peel wastes when compared with other groups. A moderate enhancement of nutrient parameters of soil was in hair and flower waste. The biological parameters growth rate, biomass gain, and cocoon production of worms in the plastic group was significantly reduced in five months of the composting period compared with other biodegradable vermicompost groups. Plastic-enriched soil showed a marked decrease in the physical, and chemical determinants of soil fertility. The present comparative study on various biodegradable wastes and plastic vermicomposting has evidenced increased soil quality parameters with biodegradable wastes and decreased content of the same because of the presence of plastic during vermicomposting.

***Keywords*:** Vermicomposting, Segregated bio-degradable waste, Plastic, Soil health parameters, Coffee waste, Vegetable peel

Soil health is the sustained capacity of soil to support all vital lives. Continuous valuation of soil quality is very important as the soil is a dynamic constituent of an environment that is endlessly varying by natural and anthropogenic activities. Currently, active research is going on worldwide to understand the quality of soil and soil microenvironment. High use of chemical fertilizers and their over-dependence have degraded the soil health resulting in the decline in soil carbon stocks (Shahane and Shivay 2021). Both globally and in India, to cater to the needs of a large population, and much dependent on chemical fertilizers than organic manure which has resulted in poor nutrient quality of soil and crops produced. The enhancement of divergence of nutrient sources in soil with importance on organic sources, adoption of principles of conservation agriculture, enhancement of soil microbial diversity, recycling of nutrients through the integrated farming system, and composting are potential choices for improving soil health (Basak et al 2021). Composting can preserve and restore soil fertility, along with the conversion of waste into a resource.

Vermicomposting is a technique that uses the earthworm to translate the voluminous waste into manure and bioremediation process that occurs due to the activity of earthworms that helps to reduce any toxicity present in the wastes. Vermicomposting is a sustainable method of improving soil health which is better than the conventional method of mixing chemical fertilizers (Siddiqui et al 2022). Earthworms and mesophilic bacteria work together in a controlled setting to break down solid biodegradable waste in a process known as vermicomposting. This procedure yields a long-lasting form of organic materials (Ahmad et al 2022).

Plastic is one of the amazing inventions by mankind ever since its initiation of use over a century ago. It has become one of the most convenient and versatile materials of interest with a wide range of applications. It is in wide usage in different industries and fields because of its properties ranging from high resistance to corrosion, lightweight, high strength, transparency, low toxicity to durability, and low manufacturing cost. Plastic has so many positive properties, but negative property contributes greatly to environmental pollution is non-biodegradability. Therefore, the high usage of plastic worldwide has resulted in extreme environmental problems (Chae and An 2018). Plastic waste is creating havoc in the environment (both aquatic and terrestrial) presently receiving universal attention. Most studies on plastic pollution have focused on aquatic environments, whereas the effects and hazards of plastic pollution of the soil are less studied. Earthworms have been largely used as the test species in studying the impact of plastic enrichment on the health of the soil and its effects on soil microorganisms,

flora, and fauna (Zhang et al 2023). Different types of organic wastes are rich in different nutrient contents. The vegetable peels are rich in minerals, flower wastes in both macro and micro-nutrients, human hair waste in nitrogen and spent coffee waste is rich in many organic compounds. The specific nutrient content of soil specifically supports the growth of some crops. However, there is limited information in the area of segregation of wastes and its impact on vermicompost and soil health. Therefore, current work focuses on the study of plastic enrichment on soil quality and its impact on vermicomposting and soil quality analysis.

MATERIAL AND METHODS

Composting: Vermicompost production was performed in plastic containers of 5 kg capacity with a working volume of 1 kg following the bed method using *Eisenia fetida*(Mulla and Pathade 2021). The experiments were in triplicates. Initially, shredded newspapers were soaked for 3 days and bedding was prepared. 1/4th of the tub was filled with the prepared newspaper bedding and above those 2 inches of jute was added. To each tub, red soil and bio-waste were added. Except for the waste, other things are common in all the groups. Treatment groups contained plastic waste and leaves, hair waste, flower waste, spent coffee waste, and vegetable peel. After adding waste in separate bins was allowed to soften for a week. Later, the earthworms whose weight and lengths were known were introduced, 20 worms in each bin and covered with coir. The lids of the bins were closed, left in dim light, and shaded closet for 5 days. Daily each group was observed for texture change, moisture content, and condition of worms. Water was sprinkled and worms were supplied with different wastes based on their requirement. Periodically, the worms were assessed for their growth pattern, reproductive rate, and health. Composting took around 4-5 months. In the end, compost was harvested, and soil analysis was done.

Effect on biological parameters: The vermicomposting process was carefully followed each day. The duration of composting, and changes like wastes, soil, and worms were periodically analyzed and recorded. The quality of the compost depends on the organic wastes used for the purpose. Different biological parameters like growth rate, biomass, cocoon production, and living conditions of the worms were studied in different experimental groups following standard protocols (Li et al 2020). The earthworms were carefully taken out of the different vermi-bed groups. Washed with tap water, and blotted with filter paper and weighed with a digital electronic balance. The weights and lengths of worms were recorded from the start of the experiment periodically up to 135 days. Each vermicomposting group was carefully analyzed for the number of cocoons, juveniles, mature worms, and dead worms. After measuring the parameters, earthworms were promptly reintroduced into the respective bins. Based on the data obtained on the biomass, cocoons, and growth rate is calculated for different vermi-bed.

Observations

Growth rate of the worms (GR) =

$$\frac{\text{Final weight} - \text{Initial weight}}{\text{Total composting time} \times \text{Average number of earthworms during composting}} \text{ (mg/worm/day)}$$

Total biomass gain (TBG)

$$\text{TBG} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \text{ mg}$$

Cocoon production ratio (PR)

$$\text{PR (cocoons/worm/day)} = \frac{\text{Number of cocoons}}{\text{Total composting time} \times \text{Average number of earthworms}} \text{ No. of cocoons/day}$$

Percentage of mortality:

$$\text{Death rate} = \frac{\text{Number of deaths during the process}}{\text{Mid process population}} \times 100$$

Vermicompost harvesting and soil analysis: At the end of 5 months, composting was completed in all the groups. Therefore, ready for harvesting. Soils enriched with compost were prepared for analysis following soil preparation protocol for physical and chemical analysis (Tan 2014). Wet samples were spread on a sheet or a plate, less than 1 cm in thickness for drying in a well-ventilated place. The drying process was observed and lumps were crushed by hands carefully and frequently. Foreign materials such as organic matter, charcoal, shells, etc were removed.The air-dried soil samples were sieved through a screen with 2 mm circular holes. Ground and sieved soil samples were stored in separate air-tight containers for further analysis. For chemical analysis of the soil, 2mm sieved soil was ground, sieved through a 0.5mm mesh screen, and stored in separate air-tight containers.

Physical Analysis of Soil (Peterson 2020)

Temperature: Three consecutive morning temperatures were determined in different soil samples at 10-15 cm depth and kept for 2 minutes.

Moisture content: Most soil analyses are made on air-dried soil, but their results are routinely expressed on the dry weight basis. Therefore, the moisture content of the air-dried soil has to be determined. The soil samples were dried at 100°C for 24 hrs in a drying oven, cooled in desiccators, and weights were obtained.

Soil moisture content of air-dried soil (%) = [(B – C)/ (B – A)] × 100

Soil moisture correction factor (MCF) = (B – A)/(C – A)

A= Constant weight of the aluminium cup

B= Weight of cup with 10grams of soil

C= Weight of oven-dried and cooled soil

The MCF is used to correct analytical results on air-dried soil to the dry weight.

Physico-chemical analysis of soil (Peterson 2020)

Electrical conductivity: The electrical conductivity of different soil suspensions was measured using a conductivity meter.

pH: Soil pH (H2O) is usually measured in a soil-water suspension of 1:2.5.

Chemical parameters: The exchangeable acidity of soils represents the acidity obtained by titrating the extracted acid with an alkali solution when neutral salts (e.g., KCl) are added to soils. It shows the amount of (a) acid substances like hydrogen ions in a soil solution and (b) hydrogen and aluminium ions adsorbed by soils (clay minerals, etc.). Hydrogen and aluminium ions are exchanged and exuded with cations contained in the soils by an ion exchange reaction. Following a standard procedure, exchangeable acidity was calculated by titrimetric method (Coscione 1998).

Total organic carbon: When organic carbon is heated with a mixture of dichromate and sulfuric acid, it is oxidized to CO_2: $2Cr_2O_7^{2-} + 3C + 16H+ \rightarrow 4Cr_2+ + 3CO_2 + 8H_2O$. Dichromate consumption is proportional to the amount of carbon reacted. By titrating the remaining dichromate with a standard iron (II) solution after the reaction, the amount of organic C is obtained (Peterson 2020).

N, P, and K analysis: The NPK in soil were analysed with rapid soil test kit for testing soil pH and NPKkit from Nice Chemicals.Soil suspension was prepared in distilled water in the ratio: 1:2 ratios in volume (i.e. one cup of soil with 2 cap water) and mixed it thoroughly. The clear supernatant was separated using filter paper. The clear soil extract was used to quantify N-P-K using reagents and followed the directions given in the manual provided with the kit.

Statistical analysis: Statistical analyses were carried out using Tukey post-tests for comparison. All statistical analyses were performed using GraphPad Prism version 5.0.

RESULTS AND DISCUSSION

Biological parameters: The growth rate of worms was significantly improved among all the compost groups compared to worms present in soil with plastic (Table 1). The maximum of 46% enhancement in the growth rate was provided by the coffee vermicompost group. Similarly, biomass gain was increased significantly in hair (18%), coffee (28%), and vegetable peel (20%). The cocoon production rate was better among all the biodegradable compost groups in comparison with plastic. The production was 2, 5, and 3 times better with flowers, coffee, and vegetable peel wastes. Many organisms depend upon the quality of the soil. To study the impact of chemical and plastic pollution, earthworms are studied as the model organisms (Chae and An 2018). Research in the area of solid waste management has enough evidence to prove how soil fertility increases with the addition of biodegradable substances (Ashraf et al 2020, Lal et al 2020). However, there is scarce data on segregated wastes, vermicomposting, and its impact on soil health parameters. Specific micronutrients, minerals, and bioactive may contribute to the quality enhancement of soil and support specific crop plants. There is not much research on separated wastes- For example flower waste from temples, vegetable peel waste from restaurants and kitchens, coffee/ tea sled waste from hotels and food industries, and hair waste from salons.. No mortality was observed in any waste. The earthworms grew rapidly and attained increased biomass and cocoon production in all biodegradable compost groups when compared to plastic. The growth rate biomass gain and cocoon production of worms present in the plastic group was not appreciable in the 5-month composting period when compared with other biodegradable vermicompost groups. Maximum weight gain and highest growth rate were attained in coffee waste. Net biomass gain/earthworm in vermicompost wastes was in the order of: (plastic=flower waste) < (hair waste= vegetable peel) < Coffee waste. Analysis of the cocoon production rate revealed that except in plastic and hair compost groups, in other groups, there was a significant increase in the reproductive rate observed. The cocoon production rate in different vermicompost wastes was

Table 1. Biological parameters of soil in different vermicompost groups

Vermicompost groups	Biological parameters		
	Growth rate of worms (mg/worm/day)	Total biomass gain (mg)	Cocoon production (Cocoons/worm/day)
Plastic	0.13 ± 0.001	11.98 ± 0.89	0.017 ± 0.00
Hair	0.19± 0.01#	14.3± 0.29#	0.018± 0.01
Flower	0.09 ± 0.011	11.47 ±1.17	0.037±0.01#
Coffee	0.19± 0.002#	15.49± 0.96#	0.06± 0.001#
Vegetable peel	0.185± 0.006#	14.51 ± 1.05#	0.046± 0.001#

Values are Mean ± SE . # Significantly different from plastic vermicompost group

in the order of: (plastic=hair waste) < (flower waste) < vegetable peel waste < coffee waste. The maximum reproduction rate of earthworms was achieved in coffee waste. All compostable wastes contain many nutrients, polysaccharides, proteins, polyphenols, tannins, fibres, and antinutrient substances. They may cause toxicity to the crop plants as such when not composted. Vermicomposting is a better method to digest the complex substances present in the wastes and convert them into simple nutrients available in the soil (Sharma and Garg 2019). Therefore positive effect of different organic substances used on the growth rate and biomass increase of *Eisenia fetida* is because of bioremediation through the vermicomposting process.

Plastics are hydrocarbons of polymeric structure enriched with additives for their special properties. After usage both petroleum-derived plastics and bioplastics become a waste that should be properly managed otherwise leads to environmental pollution. The pollution of terrestrial ecosystems directly results in changes in the chemical composition of soil and affects soil structure and functions including the effect on soil organisms. Plastics can adsorb hazardous contaminants, antibiotics, toxicants, and heavy metals (Liwarska 2021). The present study evidences that the vermicompost group with plastic enrichment resulted in a significantly decreased growth rate, biomass gain, and cocoon production rate. This stresses the fact that soil pollution with plastic is degrading the quality of soil and soil organisms like earthworms.

Physical and physicochemical parameters: The soil temperature was decreased by 14% in the plastic group whereas, increased from 7 to 26% among flower, coffee, and vegetable peel compost groups (Table 2). The electrical conductivity was marginally increased in coffee and vegetable peel compost groups. pH was not significantly changed but was slightly increased among all compost groups. Moisture content was increased by 10 to 26% among flower, coffee, and vegetable peel groups. The highest moisture content was in coffee compost soil. The moisture content of the soil decreased by 14% with plastic. Vermicompost can enhance soil fertility physically, chemically, and biologically. Physically, vermicompost-treated soil has ideal pH, temperature, moisture content, electrical conductivity, better aeration, porosity, bulk density, and water retention which enhances the growth of plants (Lim et al 2015). In present study also increased temperature and moisture content were shown in all biodegradable vermicompost groups and a significant decrease in these parameters was in the plastic group. Implying the negative effect of plastic and the positive effect of all biodegradable wastes on the physical parameters of soil quality. There was no significant difference in the parameters: pH and electrical conductivity of all the studied groups.

Chemical parameters: The exchangeable acidity of soil with plastic was not significantly different from the control group. However, it was significantly increased among all the biodegradable waste groups 39% (flower) to 67% (coffee) (Table 3 and Table 4). Total organic carbon increased marginally (14-15%) with hair and flower composts. There was a 40% increase in total carbon content because of vegetable peel. Thesignificant enhancement (76%) in this parameter was found with coffee waste composting. NPK content was also significantly improved among all biodegradable compost groups when compared to control and plastic groups. The plastic group was not significantly different from the control. Coffee waste compost gave a better result (nitrogen-high; phosphorus-very high; and potassium-high) amongst all other groups. Vermicomposting increases the acidity of the soil. Exchangeable acidity shows the amount of (a) acid substances like hydrogen ions in a soil solution and (b) hydrogen and aluminium ions adsorbed by soils (clay minerals, etc.). Hydrogen and aluminium ions are exchanged and exuded with cations contained in the soils by an ion exchange reaction. Soil exchangeable acidity regulates the amount of lime necessary to increase the soil pH which in turn will help in

Table 2. Physical and physicochemical parameters of soil in different vermicompost groups

Vermicompost groups	Physical parameters			
	Soil temperature (°C)	Electrical conductivity (mS/cm)	Soil pH	Soil moisture (% moisture content)
Control	39 ± 0.68	0.46±0.003	8.5±0.02	39.0 ± 0.68
Plastic	33.6 ± 0.52*	0.48±0.002	8.75 ± 0.01	33.6 ± 0.52*
Hair	38.7 ± 0.75	0.48±0.008	8.71±0.01	38.7 ± 0.75
Flower	43.0 ± 0.75*#	0.47±0.003	8.72 ±0.02	43.0 ± 0.75*#
Coffee	49.2 ± 0.1*#	0.48 ± 0.006	8.79 ± 0.01	49.3 ± 1.01*#
Vegetable peel	41.9 ± 0.2#	0.48 ± 0.005	8.75 ± 0.02	41.9 ± 0.2#

Values are Mean ± SE (n=3) , * Significantly different from Control; # Significantly different from plastic vermicompost group,Data was analyzed by Tukey's Multiple Comparison Test

the absorption of minerals by plants for their growth and development (Onwuka et al 2016). Total organic carbon is the carbon deposited in the organic matter and contributed by the decomposition of plant/animal matter in soil. The process of vermicomposting improves the total organic carbon content of the soil. This parameter influences many soil characteristics like water retention, aeration, and nutrient turnover (Tesfamariam 2022). Nitrogen, phosphorus, and potassium (NPK) are the main soil nutrients. These are the three essential macronutrients required for plant growth. This chemical parameter of soil helps strengthen plants' abilities to resist diseases and plays a vital role in increasing the quality and quantity of crops (Yadav et al 2020). The current study demonstrated that the vermicompost group with plastic enrichment has resulted in no change from the control group in the chemical parameters of soil quality like exchangeable acidity, total organic carbon, and nutrient indicator i.e., NPK content. All biodegradable waste vermicompost groups have shown a significant increase in the above said parameters. Thus, supporting the significance of vermicomposting in improving chemical parameters of soil and the negative impact of plastic's presence in soil during vermicomposting. To sum up the chemical characteristics of soil in different vermicompost wastes were in the order of: control=plastic < flower waste = Hair waste < vegetable peel waste < coffee waste.

Table 3. Chemical parameters of soil in different vermicompost groups

Vermicompost groups	Exchangeable acidity (centimoles/Kg)	Total organic carbon (% carbon/100 gm of soil)
Control	1.27 ± 0.04	30.13 ± 0.18
Plastic	1.25 ± 0.02	30.39 ± 0.56
Hair	2.63 ± 0.08*#	34.77 ± 0.83*#
Flower	1.77 ± 0.08*#	34.43 ± 0.72*#
Coffee	3.87 ± 0.18*#	52.9 ± 0.95*#
Vegetable peel	3.4 ± 0.26*#	42.2 ± 1.18*#

Values are mean ± SE (3 replicates in each group). Data was analyzed by Tukey's Multiple Comparison Test.
*- Significantly different compared to control; #- Significantly different compared to the plastic vermicompost group

Table 4. Nitrogen, phosphorus, and potassium contents in different vermicompost groups

Groups	NPK Content		
	Nitrogen	Phosphorus	Potassium
Control	Low	Medium*	Low
Plastic	Low	Low	Low
Hair	Medium*	Medium*	Medium*
Flower	Medium*	Medium*	Medium*
Coffee	High**	Very high**	High**
Vegetable peel	Medium*	High	Medium*

Values are Mean ± SE (n=3), *Significantly different from Control; # Significantly different from plastic vermicompost group, Data was analyzed by Tukey's Multiple Comparison Test

Generation of waste is an ecological problem but vermicomposting is a technology that utilizes this problematic waste in an eco-friendly method to generate nutrient-rich compost. This technology is appropriate due to its simplicity, cost-effectiveness, and efficiency in degrading all types of non-toxic biodegradable wastes. Numerous decomposable wastes are reported to have various nutrient proportions supporting different types of crop production (Tesfamariam et al 2022). Composting and vermicomposting both are regarded as suitable ways to manage organic waste because they not only solve waste disposal issues but also produce useful bio-amendment agents (organic fertilizer). Specifically, vermicomposting is a superior process when compared to composting, as this technique results in an increased rate of decomposition of organic matter and results in high nutrient value of soil. This is because of the beneficial bacterial interaction, and higher concentration of hormones and enzymes by the earthworms that could encourage the growth of crop plants and discourage plant pests (Wu et al 2014). Besides, vermicompost produced higher concentrations of hormones and enzymes that could stimulate plant growth and discourage plant pathogens. Therefore, in the current study, we have studied the quality of soil enriched with vermicomposting from different types of wastes like hair, vegetable peel, coffee sludge, and flowers. Plastic has also become a nuisance because of its non-biodegradability and overuse. Studies showing the impact of soil health because of plastic pollution are inadequate (Bläsing and Amelung 2018).

Vermicompost can enhance soil fertility physically, chemically, and biologically. Physically, vermicompost-treated soil has ideal pH, temperature, moisture content, electrical conductivity, better aeration, porosity, bulk density, and water retention which enhances the growth of plants (Lim et al 2015). This is demonstrated by us also as increased temperature and moisture content were shown in all biodegradable vermicompost groups and a significant decrease in these parameters was shown in the plastic group. Implying the negative effect of plastic and the positive effect of all biodegradable wastes on the physical parameters of soil quality. There was no significant difference in the parameters: pH and electrical conductivity of all the studied groups.

CONCLUSIONS

Vermicomposting is an amazing technique for increasing the nutrient content of soil. The biological parameters like the growth rate of worms, biomass gain, and cocoon production

rate augmented considerably in soil enriched with all biodegradable waste groups when compared with soil contaminated with the plastic group. The health parameters of soil like Ideal pH, temperature, moisture content, exchangeable acidity, total organic carbon, and NPK content significantly increased in soil enriched with vermicompost produced from coffee and Vegetable peel wastes when compared with other groups. The moderate enhancement of nutritive parameters of soil was seen in hair and flower waste. Considering the potential contribution to soil fertility by coffee and vegetable peel waste, there is a need to consider them for further studies and employ them in enhancing the fertility of naturally degraded ecosystems as well as agroecosystems. While plastic enriched soil showed decreased content of all the health-determining factors of the soil. Vermicomposting decreases environmental pollution and enhances soil health for sustainable development. In the future, more eco-friendly techniques to be explored to convert the enormous amount of energy present in the organic wastes to nutrients for sustainable soil health and plant growth. The comparative study of both degradable waste and non-degradable plastic waste indicates the negative effects produced by plastic on soil. There is more scope for research in this area to study and lessen the pollution caused by plastic waste and the best disposable techniques to be explored.

AUTHORS CONTRIBUTION

Dr. V Sriranjini has conceived, designed and wrote the paper. Anusha, Deekshitha and Jalaja performed the experiments and did statistical analysis.

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Impact of Manures and Nitrogen Levels on Growth and Productivity of Spring Maize (*Zea mays* L.)

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***Abstract*:** Field experiment was conducted at the Regional Research Station of Chaudhary Charan Singh Haryana Agricultural University, Karnal during 2016 and 2017 to evaluate the effect of manures and nitrogen levels on growth phenology, growth, and yield of maize (*Zea mays* L.) The experiment was laid out in a split plot design, keeping four organic manures applications as main and six fertilizers levels as sub treatment. Based on two years pooled data, different levels of manures and fertilizers levels had significant effect on various phenophases. Higher values of plant height, leaf area, leaf area index, and cob yield (with and without husk) were with the application of PM @ 7.5 t ha^{-1} and VM (@ 7.5 t ha^{-1} over FYM @ 15 t ha^{-1} and No-OM treated plots. The increase in cob yield (with and without husk) of maize with application of PM @ 7.5 t ha^{-1} over FYM @ 15 t ha^{-1} was 8.7 and 7.9%, respectively. Among the fertility levels, application of 100% RDF was at par with 75% RDF and 180 kg Nha^{-1} + 30 kg P_2O_5 ha^{-1} with significantly higher plant height, leaf area, leaf area index and higher cob yield with and without husk over rest of the treatments.

Keyords: Maize, Pressmud, Vermicompost, Phenology and yield

The profit-motivated intensified cropping system, which has high turnover of nutrients, poor recycling of organic sources and application of imbalanced fertilizers, which are more pronounced in arid and semi-arid areas leads to environmental pollution (Liu et al 2009). Increasing public awareness of the negative environmental impacts, growing consumer demand for healthier products and criticism of high input cost of production systems lead to more emphasis on organic crop production under integrated management systems. Such organic sources, viz. FYM, VM and PM improves soil structure, soil microbial activity, soil moisture conservation, source of macro and micronutrients, vitamins, enzymes, antibiotics, growth hormones and immobilized micro flora and stabilize crops productivity. Among the organic manures, FYM improves the nutrient and water holding capacity of soils, increases nutrients availability, enhance the beneficial soil microorganism activity, and improves the soil structure (Wendimu 2017). Vermicompost is a rich source of major and micronutrients and it improves the physical, chemical and biological properties of the soil (Meena and Yadav 2015). Morever, pressmud, a by-product of sugar industry serves as a nutrient rich source providing high quality organic matter when applied to the soil and results in better sustainable yield. No doubt, the cost of chemical fertilizers is increasing day by day which is not affordable by farmers and it is also undesirable due to its hazardous environmental effects (Olowoake 2014). In this respect, pressmud is a promising economic source of plant nutrients for sustainable crop production. The value of pressmud as an organic manure has been well recognized for agricultural production, as it contains substantial quantities of nutrients for improving soil fertility, physical, chemical and biological properties (Singh et al 2015). Maize (*Zea mays* L.) occupies third rank after rice and wheat and is grown all over the world in a wide range of climatic condition in sequence or as companion crop with a range of crops under different production systems due to its photo-thermo-insensitive character. In India, during past four decades intensive agriculture involving exhaustive high yielding varieties of cereals and decreasing inputs of organic sources have led to severe degradation of the soil resulting in a reduction of soil organic matter, soil fertility and productivity (Gopakkali et al 2012, Rajanna et al 2012, Choudhary and Suri 2018a, 2018b). In India, Haryana state has ample scope to increase its acreage and productivity during spring season with the introduction of high yielding single cross hybrids and suitability of maize after potato and sugarcane harvest. Keeping the above aspects in view, this study evaluated the effect of organic and inorganic nutrient sources on plant growth, phenological stages and yield on spring maize in Haryana condition.

MATERIAL AND METHODS

Experimental site: Field experiment was conducted at the

Regional Research Station of Chaudhary Charan Singh Haryana Agricultural University, Karnal (29°43"N latitude and 76°58"E longitude at an altitude of 245 meters above mean sea level) during 2016 and 2017, has semi-arid climate characterized by hot and dry summer and severe cold during winter. The mean maximum temperature is as high as 45°C during summer and minimum temperature near 0°C accompanied by frost in peak winter months of December and January. The average rainfall is about 600 mm per annum. The soil of this region is derived from Indo-Gangetic alluvium and is clay loam in texture, slightly alkaline in reaction, medium in organic carbon (0.44%) and low in available nitrogen (148.5kg ha^{-1}), phosphorus (9.3 kg ha^{-1}) and medium in available potassium(172.5 kg ha^{-1}).

Experimental procedures: The field experiment was conducted in split plot design comprising of four organic manures assisted in main plot, viz. No-OM , FYM @15 t ha^{-1},VM @ 7.5 t ha^{-1} and PM @7.5 t $ha^{-1}$and six fertilizers levels, viz.135 kg N ha^{-1} , 180 kg N ha^{-1}, 135 kg N ha^{-1} + 30 kg P2O5 ha^{-1}, 180 kg N ha^{-1} + 30 kg P2O5 ha^{-1}, 75% RDF and 100% RDF (N180 P60 K60 Zn25 kg ha^{-1}in sub plot with three replications. Maize hybrid HQPM-1 as seed material; FYM, VM and PM as organic nutrient sources and urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), murate of potash (60% K_2O) and zinc sulphate (22% Zn) as inorganic nutrient sources were used to supply nitrogen, phosphorus, potassium and zinc as per treatments.. Manures were applied 15 days before sowing as per treatment.

On well-prepared field, the sowing of single cross maize hybrid HQPM-1 was done by manual dibbling using seed @ 20 kg ha^{-1} at depth of 5-6 cm in the first week of February in both the years. The crop was sown at row-to-row distance of 60 cm and plant-to-plant distance of 20 cm. After completing manual dibbling on dry ridges, light irrigation up to half of ridges was applied in furrows on same day to ensure proper germination of seed. Full dose of phosphorus, potash, zinc and $1/4^{th}$ dose of nitrogen as per treatment were applied as basal dose at the time of sowing and remaining $3/4^{th}$ dose of N was supplied by line placement in three equal splits at different growth stages of maize *i.e.* knee high stage, tasseling and dough stage. The five irrigations at different growth stages *i.e.* four leaf stage, knee high stage, 50% tasseling, grain filling and dough stage were applied through furrow method. For growth and yield attributes were recorded from ten plants selected randomly in second row of either side in the field. The crop was harvested after full maturity *i.e.* when husk became dry which is considered the ideal stage for harvesting. Harvesting of maize from each plot was done manually. After complete drying mature cobs of each plot was weighed to record grain and stover yield.

Statistical analysis: All the recorded data were statistically analyzed using SAS 9.2 (SAS 9.2, 2009) and http://sscnars.icar.gov.in/spltfactm2s2.aspx software (SAS Institute 2001)

RESULTS AND DISCUSSION

Phenological phages: The different manures and fertility levels showed significant effect on various phenophases. Among the manures, early initiation of tasseling and silking and the lesser number of days to attain 50% tasseling and silking were with application of PM @ 7.5 t $ha^{-1}$and VM @ 7.5 t ha^{-1} and FYM @ 15 t ha^{-1} as compared to No-OM (Table 1). However, higher number of days taken to maturity recorded under PM application over No-OM. The lesser days to 50% tasseling and silking initiation in organic manures integration with inorganic fertilization may be attributed to enhanced and quick availability of plant nutrients particularly phosphorus that plays an important role in initiating primordia for the reproductive parts of the plants. Similarly, among the fertilizer levels, the application of 100% RDF, 75% RDF and 180 N + 30 P recorded lesser number of days to attain 50% tasseling. The higher number of days to attain maturity was with application of 100 per cent RDF, 135 N +30P, 180N +30 P and 75% RDF. The length of maize crop maturity period extended due to increased fertility levels and consistent availability of nutrient released from organic sources.

Growth parameter: The different manures and fertility levels significantly influenced growth parameters, viz. plant height, leaf area and leaf area index (Table 1). The PM @ 7.5 t ha^{-1} recorded the higher plant height (191.77 cm) but was statistically at par with VM @ 7.5 t ha^{-1}, but was significantly superior than FYM @ 15 t ha^{-1} and No-OM. Similar trend for leaf area and leaf area index, under organic manures. Increase in plant height might be attributed to accelerated meristematic cell division, cell elongation, adequate moisture and increased availability of essential nutrients to the maize plants thereby resulting in increased growth components *viz*. number of leaves per plant, leaf area and LAI under the PM treated plots (Gunjal and Chitodkar 2017, Raman and Suganya 2018). Similarly, higher plant height, leaf area and leaf area index were in 100% RDF, 75% and 180 N + 30 P as compared to 135 N, 180 N and 135 N + 30 P. The increase in plant height might be due to the higher nitrogen availability that accelerated cell division and enlargement, which together with the adequate quantity of potassium and phosphorus helps in the rapid cell division and better development of the cell size (Wailare et al 2017, Kumar et al 2017 and Singh et al 2017, Raman and Suganya 2018). The increase in LAI with increasing fertilizer levels was because of increased amount of cellular constituents, mainly

Table 1. Effect of organic and inorganic nutrient sources on phenological stages and growth parameters of spring maize (Pooled data over 2 years)

Treatment	Phenological phases and growth parameters					
	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm) at harvest	Leaf area (cm^2/plant) at 80 DAS	Leaf area Index at 80 DAS
Organic sources						
No-OM	71.89^{A}	75.19^{A}	108.18^{B}	175.14^{C}	6384.0^{C}	5.32^{C}
FYM (15 t ha^{-1})	70.92^{AB}	73.57^{B}	110.51^{A}	182.49^{BC}	6645.0^{C}	5.55^{B}
VM (7.5 t ha^{-1})	70.31^{B}	73.12^{B}	111.28^{A}	188.78^{AB}	6989.4^{A}	5.83^{A}
PM (7.5 t ha^{-1})	69.9^{B}	72.73^{B}	111.92^{A}	191.77^{A}	7082.8^{A}	5.91^{A}
CD (p=0.05)	1.11	1.47	2.03	8.33	182.93	0.14
NPK levels (kg ha^{-1})						
135-0-0	72.03^{A}	75.34^{A}	108.67^{c}	175.85^{C}	6471.0^{D}	5.4^{D}
180-0-0	71.5^{AB}	74.47^{AB}	109.50^{BC}	180.40^{BC}	6638.3^{C}	5.54^{C}
135-30-0	70.72^{BC}	73.59^{BC}	110.25^{abc}	185.07^{AB}	6760.0^{BC}	5.64^{BC}
180-30-0	$70.61BCD^{bcd}$	73.56^{BC}	111.00^{AB}	187.08^{AB}	6872.5^{AB}	5.74^{AB}
75% RDF	70.09^{CD}	72.67^{c}	111.40^{A}	188.75^{A}	6897.0^{AB}	5.74^{AB}
100% RDF	69.6^{d}	72.29^{c}	112.01^{A}	190.13^{A}	7013.0^{A}	5.86^{A}
CD (p=0.05)	1.06	1.4	1.89	6.88	164.25	0.13

protoplasm and due to promotion of cell division, cell enlargement, cell differentiation and cell multiplication (Singh et al 2017, Kumar et al 2017).

Yield: Significantly, higher cob yield (with and without husk) of spring maize was recorded under various organic manure sources and fertilizer levels over the No-OM during both years pooled analysis. Among the organic manures, significantly higher cob yield with and without husk was with the application of PM @7.5 t ha^{-1} and VM (@ 7.5 t ha^{-1} over the application of FYM @ 15 t ha^{-1} and No-OM. The PM @ 7.5 t ha^{-1} and VM @ 7.5 t ha^{-1} did not differ significantly in respect of cob yield with and without husk (Table 2). However, magnitude of increase in cob yield (with and without husk) of maize with application of PM @ 7.5 t ha^{-1} over farmyard manure@ 15 t ha^{-1} was 8.7 and 7.9%, respectively. This pronounced increase might be due to the application of pressmud which led to better amelioration and improvement in physical, chemical and biological properties of soil resulting in increased supply as well as uptake of nutrients that led to better growth of plants and simultaneously higher grain and biological yields (Rana et al 2018). Among fertilizers levels, significantly higher cob yield (with and without husk) was with the application of 100% RDF, 75% RDF and180 N + 30P over 135 N, 180 N and 135 N + 30 P. The treatment receiving 100% RDF registered 17.8 and 13.0% higher cob yield (with and without husk) over 135 N. Non-significant differences were noted for shelling percentage (Table 2). The different organic manures did not differ significantly in respect of shelling percentage. Although the higher shelling percentage cob was recorded under PM treatment as compared to VM and FYM application. Among the fertilizer levels, higher shelling percentage was recorded under the treatment where 100% RDF was applied as compared to rest of treatments. It might be due to adequate and readily availability of nutrients, which resulted in greater

Table 2. Effect of organic and inorganic nutrient sources cob yield and shelling percentage of spring maize (Pooled data over 2 years)

Treatment	Cob yield with husk (q ha^{-1})	Cob yield without husk (q ha^{-1})	Shelling (%)
Organic sources			
No-OM	87.06^{C}	74.85^{C}	79.65
FYM (15 t ha^{-1})	101.94^{B}	86.91^{B}	81.35
VM (7.5 t ha^{-1})	108.01^{A}	91.41^{AB}	81.49
PM (7.5 t ha^{-1})	110.77^{A}	93.79^{A}	82.39
CD (p=0.05)	5.32	4.83	NS
NPK levels (kg ha^{-1})			
135-0-0	92.06^{D}	80.58^{D}	80.64
180-0-0	98.19^{C}	84.1^{C}	81.01
135-30-0	101.78^{BC}	86.93^{BC}	81.04
180-30-0	104.9^{AB}	88.37^{AB}	81.50
75% RDF	106.21^{AB}	89.39^{AB}	81.41
100% RDF	108.49^{A}	91.07^{A}	81.73
CD (p=0.05)	4.63	3.38	NS

assimilation, production and partitioning of dry matter. Application of NPK fertilizers at different levels also had significant effect on the yields of maize (Banik and Sharma 2009, Kolawole and Joyce 2009).

CONCLUSION

The sole use of chemical fertilizers without organic manure had negative impact on soil health and productivity. Integration of organic and inorganic nutrient sources resulted in improvement in soil physico-chemical properties. Application of PM @ 7.5 t ha^{-1} being statistically similar with VM @ 7.5 t ha^{-1} and significantly effected phenological, growth and cob yield (with and without husk) of spring maize over FYM @ 15 t ha^{-1} and No-OM. Therefore, integrated application of organic and inorganic nutrient is crucial for long lasting crop cultivation.

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Relative Contribution of Different SRI Practices Towards Growth and Yield of Rice under Temperate Conditions

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Abstract: Field experiment on the relative contribution of the system of rice intensification (SRI) practices towards the growth and yield of rice was conducted at the Mountain Research Centre for Field Crops, Khudwani, Anantnag during the *kharif* seasons of 2018 and 2019. The treatments comprised a set recommended practices in which 35 days seedlings, 4 seedlings/hill at 15x15 cm spacing with, application recommended dose of fertilizers + 5t FYM/ha, chemical weed control and flooded method of irrigation was followed, replacing sequentially each conventional practice with a practice recommended under SRI in the subsequent treatments. There were nine treatments with change in seedling stage, number of seedling/hill, plant to plant spacings, farm yard manure, weed management and irrigation method . The use of young seedlings planted singly and at a wider spacing of 25 x 25 cm resulted in a significant improvement in growth and yield attributes as compared to the recommended practice. The sole use of organic manures @7.5 or 10 t/ha resulted in a significant decrease in the growth yield attributes and yield. However, combined use of all the SRI practices along with a recommended dose of fertilizers and 10 t FYM/ha resulted in a 12.5% yield increase over the recommended practice.

Keywords: Rice**,** Rice intensification**,** Organic manures**,** Plant population

Rice is the most important cereal crop of India as it is the staple food for the majority of its population. The total production of rice during 2022-23 is estimated at 135.54 million tonnes from an area of 47 million ha. The demand for rice in India is projected at 150 million tonnes by 2030. Rice is also one of the important food crops of UT of Jammu and Kashmir with a production of 58.16 lakh tonnes and an area of 2.67 lakh ha during 2020-21. Rice is a water-guzzler crop and takes 3000 -5000 L of water to produce a kg of rice. The most popular practices for growing irrigated rice crop are the continuous flooding of rice, high plant population, transplanting older seedlings, and heavy reliance on inorganic fertilizers (Thakur et al 2023). Dwindling water resources on account of increasing demand and reduced rainfall has necessitated looking for alternative methods of rice cultivation such as aerobic rice, direct seeded rice and system of rice intensification (SRI). System of rice intensification is a paradigm shift from conventional rice cultivation practices. It advocates the planting of young seedlings, singly, at a wider spacing of 25 cm x 25 cm, nourished by organic manures. Weeding mechanically, an irrigation regime of just moist soil rather than flooding, by alternate wetting and drying (AWD) is recommended (Hussain et al 2012). All these practices help in saving seed, water, improving soil fertility and increasing productivity per unit of land and water (Stoop et al 2002). The practices are of varied nature and require diverse kinds of techniques and inputs. Young seedlings, single seedling and wide spacing are non-monetary inputs but require skilled hands. Mechanical/manual weeding is labor-intensive. Organic manures are meagerly available and alternate wetting and dry methods of irrigation also demands more labour. It is imperative to identify the practices that contribute more to the growth and yield of rice so that farmers can be given a package of the practices that are feasible under a given socio-economic situation. In this backdrop drop a set of treatments was formulated, replacing sequentially each conventional practice with a practice recommended under SRI. The first treatment was a typical set of conventional practices and the last treatment a set of SRI practices. The experiment was conducted to assess relative contribution of different SRI practices towards the growth and yield of rice.

MATERIAL AND METHODS

Field experiment on relative contribution of different SRI practices towards growth and yield of rice under temperate conditions at Mountain Research Centre for Field Crops (MRCFC), SKUAST-Kashmir, Khudwani, Anantnag during *kharif* seasons 2018 and 2019. Khudwani is located between 33°70´ N latitude and 75° 10´ E longitude with an altitude of

1590 m amsl. The soil of the experimental plot was silty clay loam in texture, low in soil available N (225 kg/ha), medium in P (14.8 kg/ha) and K (220.0 kg/ha). Rainfall received during 2018 and 2019 was 390 mm and 415 mm, respectively. There were nine treatments, comprising recommended practices along with various combinations of age of seedling, seedling per hill (Table 1). *Jhelum* a high yielding with better cooking quality, greater tolerance to cold, and moderately resistant to blast was used as the test variety. A recommended fertilizer dose of 120, 60, 30 kg/ha of N, P_2O_5 and K_2O was used as per treatment details.

RESULTS AND DISCUSSION

Growth attributes: Plant height was significantly affected by various treatments (Table 2). With each level of replacing the conventional treatments with SRI treatments, there was an increasing trend of plant height up to T_4. Wider spacing resulted in a significant increase in plant height. However, sole dependence on organic manures resulted in a significant decrease in plant height. Combined use of all the SRI practices along with 10 t FYM and the recommended dose of fertilizers resulted in the production of the tallest plants. The use of single seedlings at wider spacing reduces the inter-plant competition, resulting in taller plants with a greater number of tillers. The leaf area index followed a similar trend with a gradual increase with the introduction of young and single seedlings. The increase was significant with the use wide spacing of 25 x 25 cm. Replacement of inorganic fertilisers with sole use of organic manure significantly reduced leaf area index. However, a combined application of recommended dose fertilizers along with 10 t FYM/ha resulted in the highest leaf area index. SPAD readings, an index of chlorophyll concentration in leaf, recorded at flowering stages were also significantly influenced by various treatments. With the substitution of each conventional practice with SRI practice, there was an increase in SPAD

Table 1. Treatment details

Treatment	Age of seedling (Days)	Seedlings per hill	Spacing (cm)	Nutrient management	Weed management	Water management
T_1^*	35	4	15x15	RFD+ FYM 5 t ha^{-1}	Chemical control	Submerged conditions
T_2	15	-do-	-do-	-do-	-do-	-do-
T_3	15	1	-do-	-do-	-do-	-do-
T_4	15	1	25x25	-do-	-do-	-do-
T_5	15	1	25x25	FYM 7.5 t ha^{-1}	-do-	-do-
T_6	15	1	25x25	FYM 10 t ha^{-1}	-do-	-do-
T_7	15	1	25x25	-do-	Cono weeder 2 times	-do-
T_8	15	1	25x25	-do-	-do-	Alternate wetting and drying (AWD)
T_9	15	1	25x25	RFD+ FYM 10 t ha^{-1}	-do-	AWD

*Recommended practice

Table 2. Relative contribution of different SRI practices on growth parameters of rice under temperate conditions

Treatments	Plant height (cm)	Leaf area index	SPAD	PAR (%)	No. of tillers/m^2		
					Maximum tillering	Flowering	Harvesting
T_1	117.6	4.48	35.4	88.0	399	375	358
T_2	122.0	4.48	36.1	91.0	414	385	364
T_3	122.0	4.59	36.5	91.5	411	382	365
T_4	124.5	4.83	37.5	93.0	422	388	387
T_5	107.3	4.14	29.3	84.0	380	374	368
T_6	110.8	4.32	29.9	86.0	385	370	366
T_7	123.4	4.80	33.1	89.0	416	391	372
T_8	127.5	4.98	34.0	89.5	424	397	387
T_9	130.3	5.27	38.5	95.5	447	430	410
CD (p=0.05)	5.2	0.34	2.68	4.18	15.92	15.39	14.75

readings up to T_4. However, the trend was reversed with the omission of inorganic fertilizers and the application of organic manure only. The combined application of FYM + recommended dose of fertilizers resulted in significantly higher SPAD values. The sole application of organic manure alone did not suffice the nutrient requirement of the crop as it contains a smaller amount of nutrients (Gosh et al 2022). However, the application of synthetic fertilizers in combination with organic manures had a synergistic effect on the growth attributes of the crop (Khan et al 2004). The combined application of 10 t FYM+RDF in the backdrop of all SRI practices resulted in maximum interception PAR at flowering stages (Table 2). PAR is influenced by the plant height, leaf area index and orientation of the leaves as result of taller plants, higher leaf area index and higher chlorophyll content. Periodical tiller count/m^2 revealed a decreased trend from maximum tillering to flowering which further decreased as the crop advanced to harvesting . The increase in tillers acquired statistical significance when the young and single seedlings were planted at a spacing of 25 x 25 cm. As 5 t/ha FYM + RDF was replaced by 7.5 t/ha FYM alone. There was significant decrease in the number of tillers/ m^2. Manual weeding and alternate wetting and drying also displayed some beneficial effects on the tillering behaviour. However, integrated use of 10 t/ha FYM + RDF along with all recommended practices of SRI recorded highest no. of tillers at harvest which was on an average 14.5% higher over the conventional method of rice cultivation. Young seedlings and single seedlings, planted widely with mechanical weeding, AWD combined with INM provided the best possible conditions for profuse tillering and plant growth. Young seedlings planted at the second or third phyllochron have high tillering potential (Veeramani et al 2012). SRI practices lead to tillering for a prolonged time resulting in a higher number per unit area (Thavaprakash et al 2008). INM results in an increased supply of nutrients for a prolonged time resulting in higher leaf area index and more no. of tillers and higher dry matter accumulation (Singh et al 2005, Thakur et al 2009).

Yield attributes: There was a gradual increase in number of panicles/m^2 with the replacement of 35 days old seedlings with 15 days old seedlings and 4 seedlings with 1 seedling /hill (Table 3). When 15 days old seedlings were planted singly, the number of panicles/m^2 increased more sharply and reached 382 (average). This amounted to around a 10% increase over the recommended package of practices. Transplanting young seedlings at the 2nd or 3rd phyllochron with wider spacing has higher tillering potential. Closer plants with a greater number of seedlings per hill resulted in higher below and aboveground intra-plant competition for water, light and space resulting in weak plants with less no. of tillers/hill. The higher number of tillers later translated into a higher number of panicles/m^2. The use of young seedlings with wider spacing enables the single plants to form a strong source during the vegetative phase by producing higher number of tillers (Thakur et al 2009). However, the application of FYM alone @ 5 or 10 tones/ ha resulted in a significant decrease in panicles/m^2 over T_4. Combining 10 t/ha + RFD in the backdrop of all SRI practices (T_9) resulted in a significant increase in no. of panicles/m^2, no. of grains/ panicle and 1000 grain weight (Table 4). It appears that the application of FYM alone does not suffice the nutrient requirement of the crop and INM strategy in combination with all SRI practices provides a conducive environment for high growth and yield attributes (Mangaraj et al 2022).

Table 3. Relative contribution of different SRI practices on yield attributes, yield and nutrient uptake of rice under temperate conditions

Treatment	Panicles m^{-2}	Filled grains per panicle	1000 grain weight (g)	Grain yield (t ha^{-1})	Percent change over RP	Straw yield (t ha^{-1})	N (kg/ha)	P (kg/ha)	K (kg/ha)
T_1	348	76.0	24.7	6.09	0.0	7.88	107.9	22.4	132.7
T_2	355	76.6	24.7	6.20	1.81	8.24	113.2	22.3	133.2
T_3	359	77.6	25.0	6.30	3.45	8.28	114.4	23.8	142.1
T_4	382	81.8	25.6	6.56	7.72	8.47	122.8	22.4	145.2
T_5	342	65.9	24.8	5.02	-17.57	6.96	78.1	17.1	103.4
T_6	347	70.7	23.2	5.17	-15.11	7.22	84.2	16.1	109.6
T_7	350	84.4	25.5	6.09	0.00	7.21	111.0	20.7	126.3
T_8	356	87.2	26.0	6.17	1.31	7.26	113.2	23.6	128.1
T_9	396	93.8	26.5	6.83	12.15	8.65	136.1	27.8	154.1
CD (p=0.05)	15.33	4.20	1.25	0.31		0.40	5.60	1.87	5.59

Grain and straw yield: The grain and straw yield was significantly affected by various treatments (Table 3). There was a gradual increase in grain yield with the use of young seedlings planted singly. However, the increase was sharper and significant with the widening of the spacing from 15 x 15 cm to 25 x 25 cm. The increase in the grain yield in T_4 was 0.47 t/ha amounting to 7.7% over recommended practice. The benefit of young and single seedlings planted widely was

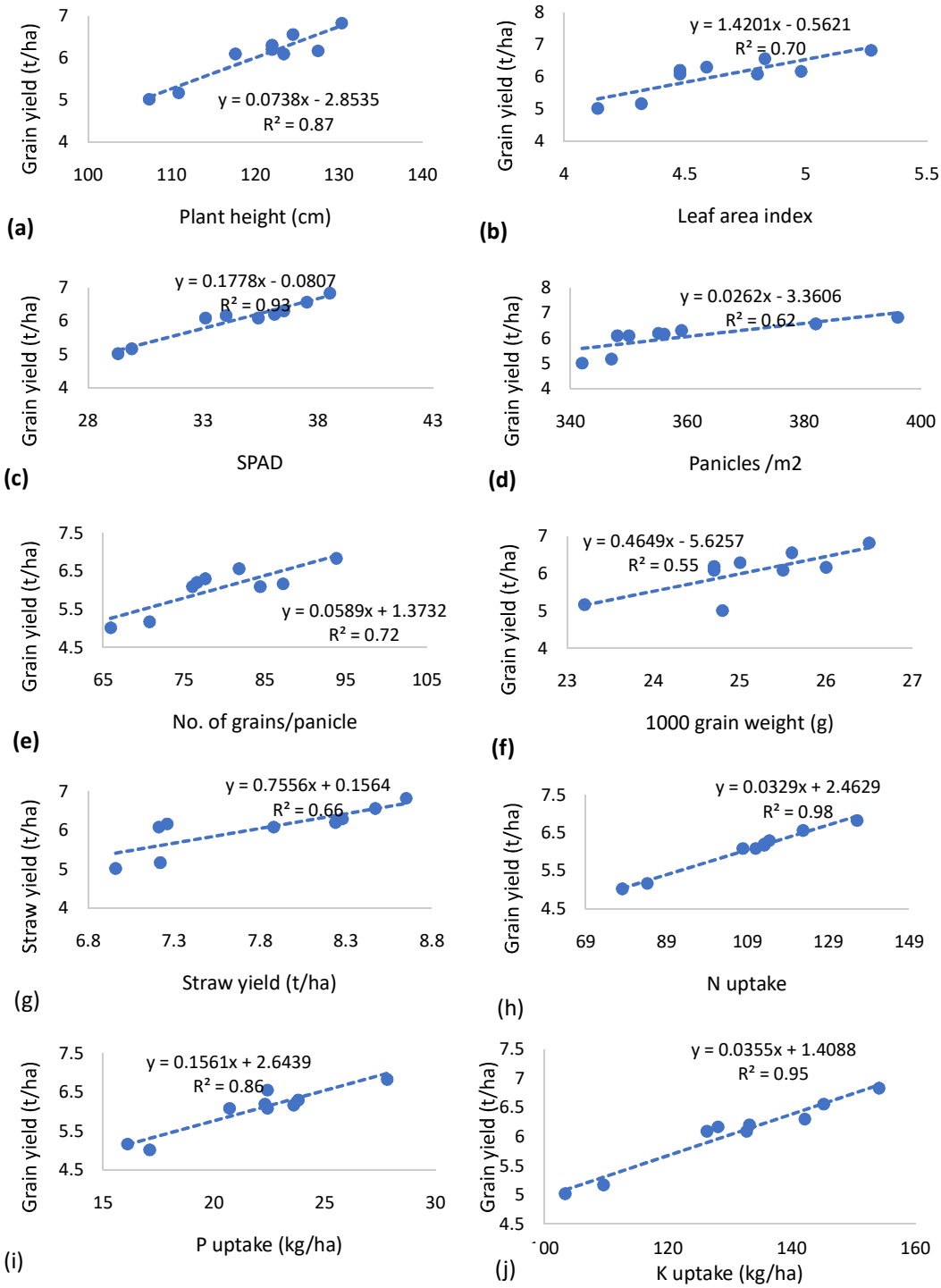

Fig. 1. Relationship of grain yield (t/ha) with plant height (cm) (a), leaf area index (b), SPAD (c), panicles/m^2(d), no of grains /panicle (e), 1000 grain weight (f), straw yield (g), Total N uptake (h), total P uptake (i) and K uptake (j)

reversed when the recommended fertilizer dose of was omitted and 7.5 or 10 t/ha of FYM was applied and there was a net drop of 15 to 17.5% decrease in yield over the recommended practice. Mechanical weeding and alternate wetting and drying resulted in an increasing trend of grain yield but a significant increase of 12.15 % was achieved only with the integrated use of 10 t/ha FYM + RFD. The use of organic manures and indigenous nutrient supply alone may not be enough to meet the large nutrient requirements of present-day high-yielding cultivars. Therefore, integrated nutrient management in which both organic manures and inorganic fertilizers are used simultaneously has been suggested as the most effective method to maintain a healthy and sustainable soil system while increasing crop productivity (Ram et al 2020, Paramesh et al 2020). Straw yield, an economically important commodity in Kashmir, was also significantly affected by various SRI practices. The use of young and single seedling/hill resulted in a 7.5% increase in straw yield over recommended practice. Using organic manures @ 7.5 to 10 t/ha alone resulted in a significant decrease in straw yield over the conventional method of rice cultivation with 5 t/ha FYM+ RDF. Use of all standard SRI practices well fertilized 10 t/ha FYM+RDF produced maximum straw yield. The increase was to the extent of 12.15% over the recommended practice. Implementation of SRI practices by using young, single seedlings planted at a spacing of 25 x25 cm, intermittently irrigated, cono-weeded and fertilized with10 t/ha FYM+RDF provided the most congenial conditions for profuse tillering (Dibakar et al 2022). Higher leaf and tiller growth resulted in more biomass accumulation a part of which was partitioned into the straw yield (Vijayakumar et al2004).

Nutrient uptake: Nutrient uptake was significantly affected by various treatments due to influence of various treatments on grain and straw yield and also due to differences in nutrient concentration of plants caused by various treatments (Table 3). The highest N, P and K uptake was observed in T_9. There was a steep decrease in nutrient uptake when only FYM was applied at 7.5 t/ha (T_5) and 10 t/ha (T_6) without RDF.

Relation between grain yield and growth and yield attributes: Grain yield had a significant and positive relation with plant height, leaf area index, SPAD, panicles /m^2, grains/panicle, 1000 grain weight, straw yield, N uptake, P uptake and K uptake. This indicates that all these parameters had a positive influence on the grain yield (Fig. 1).

CONCLUSION

The use of young, single seedlings planted at a spacing of 25 x 25 cm, rotary weeding and intermittent drainage had a synergistic role in enhancing yield by 14.5%. Thus application of organic materials such as farmyard manure considerably improves soil physical properties and nutrient uptake resulting in greater growth, yield and yield components.

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AUTHORS CONTRIBUTION

Ashaq Hussain: Conceived the idea, wrote the paper, Aabid Hussain Lone: Did the laboratory analysis of plant samples. S. Sheraz Mahdi: Did the statistical analysis, M. Anwar Bhat: Reviewed the paper and helped in statistical analysis. Intikhab Aaulam Jehangir: Helped in execution of field experiment and writing the paper

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Enhancing Productivity and Nutrient use Efficiency in Winter Maize (*Zea mays* L.) by Pant Fertilizer Band Placement cum Earthing Machine

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Abstract: The experiment was planned to study the effects of Pant fertilizer band placement cum earthing machine on performance of maize and nutrient recovery for two years at G.B. Pant University of Agriculture and Technology. Pantnagar, India. Earthing-cum- urea application was done at knee height stage by Pant Fertilizer Band Placement cum Earthing Machine with different dose of nitrogen. The grain yield, nutrient use efficiency and net return increased due to earthing-cum- urea application by Pant fertilizer band placement cum earthing machine along with a dose of 50 kg N/ha and thereafter top dressing of 50 kg N/ha at tasseling stage.

Keywords: Earthing, Maize, Mechanization, Nitrogen splitting

Maize (*Zea mays* L.) is one of the most versatile emerging crops having wide adaptability and is the only cereal crop that can be grow in different ecologies, seasons and have multiple uses. It is very popular as animal feed, fodder and industrial raw material in the developed countries whereas, in the developing or underdeveloped countries it is mainly used for food and feed. Maize is also an important industrial raw material and provides large opportunity for value addition. Maize is a heavy feeder of nutrients and hence need special care of nutrient management. Nitrogen demand of maize is very high and high rate of urea is applied to the crop requirement. Top dressing of urea in standing maize crop leads to many losses such as ammonia volatilization in high pH soils, nitrate leaching in light texture soils and denitrification in excess soil moisture condition. These losses harm the environment and disturb the whole ecology. Poor nutrient use efficiency of crops and losses of nutrients has increased the importance of proper management of fertilizers. Broadcasting of fertilizers on soil surface causes poor availability of nutrients to crop plants because of fixation of nutrients into soil and formation of many insoluble compounds. The localized nutrient application has been proved beneficial to overcome such problems. Nutrient placement in rhizosphere may be a good option to improve nutrient use efficiency and crop productivity. Localized N and P application in root rhizosphere stimulate root development and establish virtually ideal root architecture and thus increase nutrient uptake and yield of crops (Shen et al 2013). The variable effects of banding of fertilizers on crop growth suggest that the proper placement depth of fertilizers is an effective approach for improvement in crop productivity. Further, as deep bands reduce the losses of nutrients from the soil, there may be possibility to reduce the amount of applied fertilizers. In recent years, banding of fertilizers has become an emerging nutrient management strategy in maize production with the rapid development of agricultural mechanization.

Earthing up is an essential operation in maize crop which prevents the crop from lodging, provides aeration and increases grain yield (Singh et al 2016). Earthing up is a labor intensive operation which is done manually by farmers with a hoe, spade etc. which is very costly and time consuming and energy intensive. Conventionally at knee height stage top dressing is done followed by earthing. Therefore, there is need to, mechanize the top dressing fertilizer dose and earthing up in maize. Regular supply of nitrogen in adequate amount is necessary to increase the maize productivity particularly in winter season when low temperature results in slow growth rate of plants as well as poor absorption of nutrients. Top dressing of urea on soil surface is subjected to various losses such as volatilization, denitrification, leaching and thus nitrogen use efficiency become poor (Jat et al 2016). Placement of urea below the soil surface may prove an effective way to enhance nitrogen use efficiency and thus may be helpful in reducing nitrogen dose (Jat et al 2014).Therefore, keeping this view, Pant fertilizer band placement cum earthing machine was designed and developed in the Department of Farm machinery and Power

Engineering, College of Technology, G. B. Pant University of Agriculture and Technology, Pantnagar and a field study was conducted for two consecutive winter seasons to assess the impact of mechanized earthing and nitrogen splitting on maize productivity, nutrient use efficiency and profitability.

MATERIAL AND METHODS

The two years field study was conducted during winter season 2016-17 and 2017-18 at G. B. Pant University of Agriculture and Technology, Pantnagar. The experiment consisted of no earthing, manual earthing, inter-cultivation by cultivator and earthing-cum- urea application at knee height stage by Pant fertilizer band placement cum earthing machine. Total nine treatments were executed in randomized block design with three replications (Table 1). Inter-cultivation by cultivator and earthing treatments (manual and by machine) were imposed at knee height stage (94 and 91 days after sowing in both the years, respectively). Except machine treatments, urea was applied @ 50 kg N/ha manually at knee height stage in all the treatments. At tasseling stage, urea was applied manually in all the treatments. Entire amount of P_2O_5 (60 kg/ha) and K_2O (40 kg/ha) and 22.5 kg N /ha were applied as basal. Nitrogen @ 27.5 kg/ha was applied manually at 4-leaf stage in all the treatments. Thus total amount of nitrogen was 110 kg/ha in T_2, 130 kg/ha in T_1, T_4 and T_6 and 150 kg/ha in remaining treatments. The sources of nutrients were NPK fertilizer (12:32:16), urea and muriate of potash. The soil was sandy loam in texture, neutral in reaction (pH 7.3), medium in organic carbon (0.68 %), low in available nitrogen (226 kg/ha), medium in available phosphorus (19.6 kg/ha) and potassium (167 kg/ha).The crop was sown at planting geometry 75 cm × 20 cm on 15 November and 19 November in 2016 and 2017 and harvested on 3rd May 2017 and 1st May 2018, respectively. Hybrid variety NMH 920 was grown as per recommended practices. One pre - sowing irrigation (6 cm) was given to bring the field into optimum moisture condition for germination. The field was prepared by three harrowing and one levelling. Pre-emergence application of atrazine @ 1.0 kg a.i./ha was done next day of sowing. One hand hoeing was also done in all the treatments at 58 and 54 days after sowing in both the years, respectively. The crop was irrigated six times (6 cm each) in both the years. The size of gross and net plots was 15 and 7.2 m^2, respectively. The cobs were harvested manually and were shelled when grain moisture content was about 15 per cent. Stover yield was recorded after sun drying. Nutrient use efficiency for N, P and K was calculated in terms of partial factor productivity (PPF) by dividing yield by respective nutrient dose. Cost of cultivation was calculated by considering current market prices of inputs in local market. Monetary return was obtained by considering market price of grain i.e. Rs. 20/kg. Benefit to cost ratio (B:C) was obtained by dividing net return by cost of cultivation. The data were analyzed by using the online statistical software OP Stat (*Sheoran* et al *1998)*.

Pant fertilizer band placement cum earthing machine (Fig. 1) is a tractor drawn machine which can perform the three main functions, (i) loosening of the soil up to 200 mm depth and cutting the weeds, (ii) placement of chemical fertilizers on the surface of the soil near the plant at a distance

Table 1. Growth response of winter maize to earthing and nitrogen dose

Treatment	Plant height (cm)	Plant population (× 10^3)/ha	No. of cobs (× 10^3)/ha	Days to 50%		Individual cob weight (g)
				Tasseling	Silking	
T_1: Machine Earthing 30 kg N at KH + 50 kg N at tasseling	156.5	61.9	59.4	120.0	123.7	110.6
T_2: Machine Earthing 30 kg N at KH + 30 kg N at tasseling	154.4	62.9	60.7	120.3	123.7	98.4
T_3: Machine Earthing 50 kg N at KH + 50 kg N at tasseling	164.5	61.8	59.9	120.0	124.0	128.3
T_4: Machine Earthing 50 kg N at KH + 30 kg N at tasseling	160.1	61.9	60.5	120.7	123.7	103.9
T_5: Machine Earthing 70 kg N at KH + 30 kg N at tasseling	166.3	61.3	59.2	120.0	124.0	128.5
T_6: Machine Earthing 70 kg N at KH + 10 kg N at tasseling	159.7	61.2	59.7	120.7	124.0	102.2
T_7: Manual earthing	158.7	61.4	59.8	121.0	124.0	110.0
T_8: Inter-cultivation by cultivator	155.6	62.0	59.8	120.0	123.7	108.0
T_9: No earthing	154.5	61.4	60.1	120.3	123.7	102.5
CD (p = 0.05)	4.6	NS	NS	NS	NS	15.5

Machine: Pant fertilizer band placement cum earthing machine, KH: knee height stage

Fig. 1. Pant fertilizer band placement cum earthing machine

of 50-100 mm sideways (iii) earthing-up the plant and covering the fertilizer. The mounting of legs on the frame is such that they can be adjusted in horizontal and vertical plane according to row crop spacing and depth of operation. The working efficiency of machine is 0.75 ha/hr. The machine offers the apparent advantage of timely earthing, weeding, saving of time, fuel and labour costs and therefore, helps reducing the cost of production besides reducing the drudgery of the task.

RESULTS AND DISCUSSION

Growth and development: Mechanized machine earthing with 70 kg N at knee height stage + 30 kg N at tasseling produced significantly taller plants than other treatments except it was on par with machine earthing with 50 kg N at knee height stage + 50 kg N at tasseling (Table 1). Earthing up ensures better aeration and fine tilth in root zone and thus makes favourable conditions to the development of roots. These conditions might result into higher water and nutrient uptake by roots from soil and favoured shoot growth. Further, adequate amount of nitrogen in these treatments helped in better growth. In machine treatments, applied urea was covered by soil and was available to roots. Moreover, band application of urea near to roots facilitated nitrogen acquisition by plants. Chances of gaseous loss of machine applied urea were less because it was properly covered by soil which probably helped in more availability of nitrogen. These conditions might resulted into higher shoot growth and thus more plant height. Similar findings were reported by Painyuli et al (2013).

Planting geometry in all treatment was same which led to at par variation in plant population. Number of cobs per unit area depends on plant population and number of cobs per plant. Non-significant differences in plant population caused statistically same number of cobs/ha among all treatments. Different treatments failed to bring significant differences for days to reach 50% tasseling and 50% silking. Crop took 120 days to reach 50% tasseling while 50% silking stage was attained 3-4 days after 50% tasseling. It indicated that phenology of maize was not altered due to earthing operations and nitrogen dose.

Yield attributes and yield: The yield contributing characters viz., cob length, cob girth, cob weight and 100- grain weight were significantly affected by treatments (Table 2). Yield attributes were significantly more in machine earthing with 50 kg N + 50 kg N at tasseling, and was statistically on par with machine earthing with 70 kg N + 30 kg N at tasseling however, cob length was also statistically on par with manual earthing and cob girth with manual earthing and machine earthing with 50 kg N + 30 kg N at tasseling. Individual cob weight improved significantly due to different tested treatments. Mechanized earthing with 70 kg N at knee height stage + 30 kg N at tasseling gained the maximum individual cob weight (128.5 g). It was statistically at par with mechanized earthing with 50 kg N + 50 kg N at tasseling but had significantly higher cob weight than the remaining treatments. Higher individual cob weight under these treatments was because of higher cob length, cob girth as well as its heavier grains as reflected by 100- grain weight.

Compared to manual earthing, mechanized earthing with 50 kg N + 50 kg N at tasseling achieved 16.6 % heavier cob weight. Better shoot growth under earthing operation specially in machine earthing helped in improving yield attributes. Mechanized earthing with 50 kg N at knee height + 50 kg N at tasseling produced the maximum grain yield (5712 kg/ha) and was on par with 70 kg N at knee height by machine + 30 kg N at tasseling. It recorded significantly higher grain yield than all other treatments. The increase in yield under this treatment was 15.8, 18.5 and 23.5 % more compared to manual earthing, inter-cultivation by cultivator and no earthing, respectively. The higher yield attributes under mechanized earthing resulted into more grain yields. The higher weight of cob under mechanized earthing resulted into more grain yields. Similar results were reported by Bhatnagar and Kumar (2017) and Nath et al (2020). Manual earthing had an edge over no earthing as well as inter-cultivation by cultivator for grain yield but variations were not enough to be significant. Numerically manual earthing improved the grain yield by 6.7% over no earthing treatment. Among mechanized earthing treatments variations in grain yield were due to variation in N dose as mode (mechanized) and timing of N application (knee height and tasseling stage) was

similar in all mechanized earthing treatments. Nitrogen application @ 50 kg/ha at knee height stage and 50 kg/ha at tasseling stage produced statistically at par grain yield with mechanized earthing with 70 kg N at knee height and 30 kg/ha at tasseling stage although former treatment has numerically higher grain yield by 2.7 % over later treatment indicated that optimum dose of N application at tasseling is also essential to get higher productivity. In remaining mechanized earthing treatments, reduction in grain yield was owing to reduction in N dose (Table 1). Stover yield also exhibited the similar trend like grain yield. The highest stover yield (10398 kg/ha) was obtained with application of 50 kg/ha N at knee height and 50 kg /ha N at tasseling stage followed by mechanized earthing. Harvest index remain unaffected dose to different treatments.

Nutrient use efficiency: Nitrogen use efficiency in terms of partial factor productivity of nitrogen (PPF_N) was the lowest (30.8 kg grain/kg N) in no earthing treatment (Table 3). All treatments except T6, T7 and T8 showed significantly superiority over T9. The highest PPF_N was recorded in T2 (40.2 kg grain/kg N). Compared to no earthing treatment, partial factor productivity of phosphorus (PPF_P) and potassium (PPF_K) was significantly higher only in T3 and T5 being maximum in T3 (218 kg grain/kg P and 172.1kg grain/kg K, respectively). PPF is calculated by dividing yield by nutrient dose. Therefore, low nutrient dose and height yield are associated with higher nutrient use efficiency. Nitrogen dose was the lowest in T2 which caused more PPF for nitrogen. A negative relationship between nutrient amount and nutrient use efficiency has been reported by many researchers (Srivastava *et al*., 2018). Phosphorus and potassium doses were similar in all treatments so differences in PPF of P and K were only because of variation in grain yield. Since, treatment consisting of 50 kg N at knee height by machine + 50 kg N at tasseling attained maximum grain yield hence it had the highest PPF_P and PPF_K.

Economics: In comparison to no earthing treatment, none of the treatments showed economic superiority except

Table 2. Effect of earthing and nitrogen dose on yield attributes, grain yield and stover yield and harvest index of winter maize

Treatment	Cob length (cm)	Cob girth (cm)	100-grain weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
T_1	14.3	13.2	25.7	4900	8949	35.3
T_2	13.6	13.0	24.9	4424	7935	35.7
T_3	16.1	14.0	27.7	5712	10398	35.4
T_4	14.9	13.6	26.3	4649	8356	35.7
T_5	16.0	14.0	27.4	5560	10125	35.5
T_6	14.4	13.4	26.0	4545	8213	35.6
T_7	15.4	13.6	26.5	4933	8815	35.8
T_8	15.0	13.5	25.8	4821	8671	35.7
T_9	14.3	13.5	24.6	4625	8320	35.7
CD (p=0.05)	0.7	0.4	0.9	581	620	NS

For treatment details see Table 1

Table 3. Nutrient use efficiency and economics of winter maize as affected by earthing and nitrogen dose

Treatment	Partial factor productivity			Net return (Rs./ha)	B:C ratio
	N	P	K		
T_1	37.7	187.0	147.6	58602	1.49
T_2	40.2	168.9	133.3	49345	1.26
T_3	38.1	218.0	172.1	74592	1.88
T_4	35.8	177.4	140.0	53591	1.36
T_5	37.1	212.2	167.5	71551	1.80
T_6	35.0	173.5	136.9	51511	1.31
T_7	32.9	188.3	148.6	52665	1.14
T_8	32.2	184.0	145.2	56212	1.40
T_9	30.8	176.6	139.3	53491	1.37
CD (p=0.05)	4.3	22.2	17.5	11628	0.28

For treatment details see Table 1

mechanized earthing with 50 kg N at knee height by machine + 50 kg N at tasseling and 70 kg N at knee height by machine + 30 kg N at tasseling (Table 3). Machine earthing with 50 kg N + 50 kg N at tasseling fetched significantly higher net returns (Rs. 74592/ha) than rest of the treatments but did not vary statistically with machine earthing with 70 kg N + 30 kg N at tasseling. Net return under machine earthing with 50 kg N + 50 kg N at tasseling was Rs. 21927, 18380 and 21101/ha higher as compared to manual earthing, inter-cultivation by cultivator and no earthing, respectively. Manual earthing had the lowest B:C ratio (1.14) because of more money spent on labourers. mechanized earthing with 50 kg N + 50 kg N at tasseling recorded highest B:C ratio (1.88) and was at par with machine earthing with 70 kg N + 30 kg N at tasseling. These results corroborate the findings of Nath et al (2020) who noted more net return in earthing up operation in maize.

CONCLUSION

From this study it can be inferred that earthing by Pant fertilizer band placement cum earthing machine has potential to increase the nutrient use efficiency and growth of maize in winter season. Use of Pant fertilizer band placement cum earthing machine in winter maize at knee height stage along with application of 50 kg N/ha and thereafter top dressing of 50 kg N/ha at tasseling stage is beneficial to increase grain yield and monetary return.

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Variable Irrigation Phasing and Establishment Techniques in Chickpea (*Cicer areitinum* L.) under Sprinkler and Flood Irrigation System in Tarai Region of Uttarakhand

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***Abstract*:** Chickpea is a water sensitive crop, hence requires judicious water management to harness reasonable productivity from this crop. Therefore, a study was conducted in sandy loam soil to find out the effect of irrigation schedules, establishment methods and irrigation methods on yield, water saving, IWP and energy use efficiency of chickpea in sandy loam soil at GBPUAT, Uttarakhand from 2016-17 to 2018-19. The experiment consisted of three irrigation schedules (irrigation at branching, pod development and at both stages), two establishment methods (flat and raised bed) and two irrigation methods (flood and sprinkler irrigation) . Irrigation at both branching and pod development stages produced the highest chickpea grain yield. One irrigation at either stage saved 50% of irrigation water compared to irrigation at both stages. Raised bed and sprinkler irrigation method saved 18.8 and 29.5%irrigation water, respectively. Raised bed method and sprinkler irrigation method showed their superiority over flat bed and flood irrigation, respectively for irrigation and economic water productivity. Energy use efficiency of irrigation scheduled at either stage of crop growth was higher than irrigation at both stages but at the expense of yield. Raised bed method and sprinkler irrigation method were most energy efficient.

Keywords: Chickpea, Grain yield, Raised bed, Sprinkler irrigation, irrigation schedule, Water saving, Energy

Chickpea is the major pulse crop of India sharing approximate 37% in total area under pulses (Indiastat 2021) and is primarily grown as rainfed crop that typically rely on the residual soil moisture from the preceding season (Ramamoorthy et al 2017). It may be subjected to moisture stresses (excess and deficit) due to low and erratic distribution of winter rainfall which affects optimum plant stand in early stage and poor seed setting during later stages. Chickpea may also face terminal drought leading to forced maturity. Conventionally, chickpea is irrigated by check basin irrigation method (5-6 cm depth) in flat land configuration. This approach requires huge amount of water and is usually detrimental for root growth and nodule formation due to water stagnation in the root zone. Chickpea plants turn yellow due to decrease in photosynthesis under flooding which can hamper the overall crop growth and productivity (Komatsu et al 2021). Usually root growth and nodulation of chickpea; irreversibly destroyed by mid and terminal water logging (Worku 2016). The best possible approach to alleviate the illustrated problems is to provide controlled depth of irrigation which can be ensured by modifying land forms and adopting suitable irrigation method. Growing of chickpea on raised beds could improve the management of irrigation water and depth of applied water could be controlled more precisely. Crop roots do not have to face stagnated water conditions so plant growth does not hamper and ultimately crop yield increases. Kumar et al (2015) observed 20.2% increase in grain yield of chickpea grown on 75 cm wide raised beds as compared to flat bed planting. Sprinkler irrigation has the provision to apply controlled quantity of irrigation water and this not only saves a substantial amount of water but sensitive crops like pulses are unlikely to suffer. The importance of applying irrigation would be dented if not given at critical stages, as irrigation at these stages results into maximum output per unit water applied. Irrigation at flowering and pod development stages to chickpea increased grain yield to the tune of 7 and 27%, respectively over no irrigation (Singh et al 2015). Considering the above, the present investigation was carried out to verify the hypothesis that bed sowing, proper irrigation scheduling and sprinkler irrigation in chickpea would save irrigation water besides improving the crop and irrigation water productivity.

MATERIAL AND METHODS

Experimental site and soil: A three-year field experiment was conducted during Rabi season through 2016-17 to 2018-19 at GBPUAT, Pantnagar which is located at 29°N latitude and 79.5°E longitude and at an altitude of 243.8 m above mean sea level in the Tarai region of Himalayas (Fig. 1). The soil of the experimental field was sandy loam in texture and neutral in reaction (pH-7.5), medium in organic carbon (0.71%), low in available nitrogen (180.4 kg/ha), high in

available phosphorus (22.8 kg/ha) and medium in potassium (265.6 kg/ha). Field capacity moisture of the field was 20.4% and PWP moisture was 8.4%.

Weather conditions: The study site is characterized by sub-humid and sub-tropical climate. Region has cold winters and hot, dry summers. During summer season, the maximum temperature exceeds 40°c in June while in winter, the minimum temperature touches 0 °c occasionally during January. The mean weekly weather data prevailing during the course of experiment (November to April of 2016-17, 2017–18, 2018-19) were obtained from the meteorological observatory located at Norman E. Borlaug Crop Research Centre, Pantnagar. During the first year of the study (2016-17), 75.2 mm rainfall was received against total water loss of 269 mm through evaporation. Due to good rainfall in the month of January (60.4mm), irrigation was skipped at the branching stage (Table 1). This way, crop under branching stage treatment was rainfed. In II and III year, the rainfall received during the growing period was 13.6 and 57.8 mm, respectively.

Treatments and experimental design: Experiment comprising three irrigation schedules (irrigation at branching stage, pod development stage and both at branching and pod development stages), 2- establishment methods(flat and raised bed) and two irrigation methods (flood and sprinkler irrigation) was arranged in factorial RBD design with three replications. Thus, the experiment was comprised of total 12 treatment combinations.

Crop management: Land preparation as well as execution of treatments was done manually. In flat bed sowing, furrows were opened manually with a furrow opener at 30 cm distance. Chickpea variety "Pant gram-186"was sown @ 80 kg/ha in the first fortnight of November and harvested in the first fortnight of April. Raised beds were prepared manually with spade having a 90 cm distance between centers of one furrow to another furrow. The width of the bed top was 65 cm having a furrow width of 25 cm. Three rows of chickpea were accommodated per bed, so that plant population remained the same in both the land configurations. The crop grown on flat beds was fertilized with 25 kg N/ha, 60 kg P_2O_5/ha and 40 kg K_2O/ha while two third doses of fertilizers were applied in raised bed conditions as compared to flat bed. For sprinkler irrigation, four sets of micro sprinklers having diameter 4.0 m were placed per plot. The irrigation depth was 5 cm in flat and 3.5 cm in raised bed. The irrigation depth of 3 cm was maintained in sprinkler method for both the establishment methods. Measured quantity of irrigation water was worked out by using standard flow (discharge) rate equation for open channel. The time of irrigation application was calculated as follows:

Time (minutes) = [Depth of irrigation (mm) x area of plot (m^2)]/discharge per min (L min^{-1})

Yield estimation: The grain yield was estimated from a harvested area of 8.0 m^2 (2.1 m × 4 m). The grain biomass yield was adjusted at 14% moisture content and expressed in Mg ha^{-1}

Irrigation water saving, irrigation water productivity and economic water productivity: Total irrigation depth for each year was calculated by summing up the total amount of irrigation water applied in every treatment (Table 3). Water saving in treatments where irrigation was provided at a single stage was calculated against the treatment where irrigation was provided at both stages. For establishment methods, water saving was calculated in raised bed against flat bed method while water saving through sprinkler irrigation was worked out against flood method (Table 3). Irrigation water productivity (IWP) and economic water productivity (EWP) were calculated and the mean of the three years is presented. For the treatment where irrigation scheduling was done only at branching stage, the mean of the year 2017-18 and 2018-19 was taken as crop received rainfall at branching stage in the first year of the study.

$$\text{IWP (kg/ha - mm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total irrigation applied (mm)}}$$

$$\text{EWP (Rs/mm)} = \frac{\text{Net return (Rs/ha)}}{\text{Total irrigation depth (mm)}}$$

Economics*:* The economics of treatments was computed on the basis of prevailing market rates of the different commodities.

Energy analysis: Energy used and produced in each treatment was computed using the standard procedure.

Input energy: Input energy was calculated by multiplying energy equivalent per unit of input (Table 1) with the amount of inputs (Table 2) used in various operations performed for growing chickpea under different treatments.

Output energy: Output energy of grain was calculated by multiplying grain yield (kg/ha) obtained under respective treatment with 14.7 ***MJ/kg.***

Energy parameters: By using input energy and output energy, energy use efficiency, specific energy and energy productivity were calculated as follows.

$$\text{Energy use efficiency} = \frac{\text{Total energy output (MJ/ha)}}{\text{Total energy input (MJ/ha)}}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total energy input (MJ/ha)}}$$

$$\text{Specific energy (MJ/kg)} = \frac{\text{Total energy input (MJ/ha)}}{\text{Grain yield (kg/ha)}}$$

Net energy gain (MJ/ha) = Energy output (MJ/ha) – Energy input (MJ/ha)

Statistical analysis: Data were analyzed using analysis of variance technique appropriate to Factorial RBD using R software. The least significant differences (LSD) at 5% level of probability were calculated for testing the significance of difference between any two means.

RESULTS AND DISCUSSION

Grain yield: Chickpea grain yield did not exhibit significant variations due to change in establishment methods as well as irrigation methods. Average grain yield in flat (1562 kg/ha) and raised bed (1572 kg/ha) establishment methods was almost comparable. Sprinkler irrigation produced 4.4 % higher grain yield as compared to the flood method. Availability of optimum soil moisture is crucial for getting higher yield in chickpea. Management options such as sowing of seeds on raised bed or use of sprinkler irrigation method ensure to maintain moisture at optimum levels. Relatively higher chickpea grain yield under sprinkler irrigation compared to flood irrigation method was due to maintaining good aeration in root zone as compared to flooding even after providing the required amount of water for crop growth throughout the growing season. Micro sprinklers provided optimum depth of irrigation which resulted in adequate soil moisture status in the root zone throughout the crop growth period. Moreover, the micro-climatic conditions in terms of reduced temperature and increased relative humidity in crop canopy are also favored by applying water in sprinkle form. Further, relatively more compact soil in the check basin plots may pose mechanical resistance and hinder exchange of air in the rhizosphere leading to reduced crop yields.

Irrigation applied at both branching and pod development stages did not increase the grain yield significantly over irrigation at pod development stage only but out-yielded the

Table 1. Energy equivalents of different inputs and output

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Reference
Input			
Human (adult man)	Man- hour	1.96	Rafiee et al (2010)
Diesel	litre	56.31	Canakci and Akinici (2006)
Electricity	Watt	16.93	Mobtaker et al (2010)
Chickpea seed	kg	14.7	Kitani (1999)
Water	m^3	1.02	Rafiee et al (2010)
Fertilizer N P K	kg	60.6 11.1 6.7	Gundogmus (2006)
Machinery Electric motor Farm machinery	kg	68.40 62.10	Rafiee et al (2010)
Output			
Chickpea grain	kg	14.7	Kitani. (1999)

Table 2. Crop management details

Treatment	No. of tillage operations			Seed rate (kg/ ha)	NPK dose	Total irrigation volume (m^3) and time taken (hr)	Drying and packagi ng
	Harrowing	Planking	Raised bed formation				
Vegetative+flat+ flood	03	1	-	80	25:60:40	500 (15hr)	4 labor
Vegetative+flat+ sprinkler	03	1	-	80	25:60:40	300 (9hr)	4 labor
Vegetative+raised bed+flood	03	1	1	80	17:40:27	350 (10.5hr)	4 labor
Vegetative+raised bed+sprinkler	03	1	1	80	17:40:27	300 (9 hr)	4 labor
Pod devel.+flat+flood	03	1	-	80	25:60:40	500 (15 hr)	4 labor
Pod devel.+ flat+ sprinkler	03	1	-	80	25:60:40	500 (15 hr)	4 labor
Pod development+raised bed+flood	03	1	1	80	17:40:27	350 (10.5 hr)	4 labor
Pod development+raised bed+sprinkler	03	1	1	80	17:40:27	300 (9 hr)	4 labor
Both+flat+flood	03	1	-	80	25:60:40	1000 (30 hr)	4 labor

treatment where, irrigation was applied only at vegetative stage. Irrigation scheduled at both branching and pod development stages produced significantly higher grain yield as compared to irrigation at branching stage. Irrigation at both stages increased the grain yield by 13.2 and 8.7% over irrigation at only vegetative and pod development stage, respectively. Irrigation imposed at the pod development stage only also improved chickpea grain yield by 4.2% over branching stage irrigation. Irrigation provided at the pod development stage or both the stages contributed to better translocation and partitioning from source to sink resulted in better yield attributes and subsequently the crop productivity. It may infer that residual moisture from previously grown crop; can fulfill the crop demand during early phases of crop growth but during the pod filling stage the crop may experience terminal drought. This situation could hamper the seed filling. Singh et al. (2010) also reported the terminal moisture stress is the major constraint in achieving potential yield of chickpea. Irrigation provided only at vegetative stage was not able to bring irrigation induced yield advantage as moisture stress at subsequent stages can disrupt the metabolism of carbohydrates. It might have resulted in decreased transportation of water soluble carbohydrates (El Habti et al. 2020).Moisture stress at pod development stage of legumes delays the cessation of flowering and causes embryo abortion thereby reduces the overall pod development and ultimately results in reduction of grain yield (Ntukamazina et al., 2017). Irrigation provided only at pod development stage also experienced slightly lower productivity than the treatment where irrigation provided at vegetative as well as pod development stage.

Irrigation water saving: For first year of the study, irrigation water saving due to application of irrigation at various irrigation stages was not computed as crop received substantial amount of rainfall (60.4mm) in the month of January, hence supplemental irrigation during the vegetative growth phase was skipped. In the years 2017-18 and 2018-19; single irrigation given either at branching or pod development stage saved 50.0% irrigation water as compared to two irrigations at both branching and pod development stages due to net saving of one irrigation. The three years' study suggested that sowing chickpea on raised beds saved around 18.8 % irrigation water as compared to flat sowing. Chickpea irrigated through sprinkler method saved about 29.5 % irrigation water against flood irrigation method. Chickpea grown on raised bed saved irrigation water as compared to flat bed as in case of raised bed sowing; less depth of irrigation water (3 cm) was applied only in the furrows. It ultimately resulted in reduction in total volume of applied water. Kumar et al. (2015) also reported 26.2 % irrigation water saving in chickpea crop grown on raised beds as compared to flat bed sowing. Water saving in sprinkler irrigation against flood method was observed as water distribution by sprinkler method was more even and it applies less irrigation depth (3 cm) than flood method (5 cm) to irrigate the same area.

Irrigation water productivity: Irrigation water productivity indicated that single irrigation at pod development stage recorded the maximum irrigation water productivity (42.4 kg/ha-mm) followed by irrigation at branching stage (39.8 kg/ha-mm). Chickpea irrigated twice at vegetative and pod development stages recorded the lowest irrigation water productivity (31.4 kg /ha-mm). Irrigation at pod development did not bring significant reduction in the yield from the treatment where irrigation was applied at both vegetative and pod development stages; as well as irrigation water applied was 50% lesser which ultimately enhanced irrigation water productivity. Raised bed land configuration (40.7kg /ha-mm) enhanced the irrigation water productivity by 19.4% over flat sowing (32.8 kg /ha-mm). Crop irrigated through sprinklers recorded 32.9% higher irrigation water productivity than flood irrigation method. Comparable yield to flat method was produced under raised bed method with less application of water so irrigation water productivity was higher. Similar trend was obtained for the sprinkler irrigation method as compared to flood irrigation.

Economic water productivity: Economic water productivity was maximum (1072 Rs. /mm) when irrigation was applied at the pod development stage with higher net return per mm of water than two irrigations at vegetative and pod development stages. Raised bed and sprinkler irrigation earned 183 and 450 Rs. /mm higher economic water productivity than flat sowing and flood irrigation, respectively. Economic water productivity of raised bed as well as sprinkler irrigation method was also higher as EWP is the cumulative function of net return as well as total irrigation depth by the respective treatment. Relatively lower irrigation depth with good net return resulted in higher economic water productivity under raised bed and sprinkler irrigation treatments.

Economics: The highest net return (46470 Rs. /ha) was obtained when two irrigations were applied at both branching and pod development stages and was significantly higher than single irrigation either at vegetative or pod development stage. Flat sowing of chickpea gave almost similar net return with a very little margin of 462 Rs. /ha over raised bed sowing method. Net return was also statistically at par due to use of flood or sprinkler irrigation methods. B:C was maximum (1.52) with twice irrigation at branching and pod development stages and was 17.8 and 15.1 % higher than single irrigation either at branching or pod development stage, respectively.

Input energy: Irrigation applied at both stages; required about 34.9% more energy than the irrigation at either stage of the crop growth. Among different establishment methods; the crop grown on raised bed was more energy efficient as for crop growing on flat bed 21.7% more input energy was needed. Input energy consumption in flood method of irrigation was about 30.7% more than sprinkler irrigation method (Table 5). Despite the requirement of additional energy of 610 MJ/ha for raised bed preparation, the highest input energy (20161 MJ/ha) was observed when sowing was done on flat bed and flood irrigation was provided at both stages of crop growth. In this treatment, the maximum share (65.2%) in total energy was of irrigation water energy. Minimum input energy (9606 MJ/ha) was observed for the treatment where sowing was done on flat bed and a single irrigation was provided by using sprinkler method (Fig. 2). Despite more energy consumption for land preparation in the raised bed method, total input energy was lower than the flat bed method as irrigation water energy was considerably low. In single irrigation by flood method under raised bed as well as flatbed conditions an additional volume of 150m^3 water was provided in flat bed conditions along with 4.5 more hours for operating the pump which resulted in 96.8% increase in the irrigation water energy. Apart from this the input energy for fertilizer application was also lower under raised bed method. Input energy use under the sprinkler method was

Table 3. Irrigation depth applied and corresponding irrigation water saving in different treatments

Treatment	Irrigation depth (mm)			Irrigation water saving (%)			Mean irrigation water saving
	2016-17	2017-18	2018-19	2016-17	2017-18	2018-19	
Irrigation stage							
Branching	-	36.3	36.3	-	50	50	50
Pod development	36.3	36.3	36.3	-	50	50	50
Branching +Pod development	36.3	72.6	72.6	-	-	-	-
Establishment method							
Flat	40.0	53.3	53.3	-	-	-	-
Raised bed	32.5	43.3	43.3	18.8	18.8	18.8	18.8
Irrigation method							
Flood	42.5	56.7	56.7	-	-	-	-
Sprinkler	30.0	40.0	40.0	29.5	29.5	29.5	29.5

Table 4. Productivity, water use parameters and economics as influenced by various treatments

Treatment	Grain yield (kg/ha)	Irrigation water productivity (kg/ha-mm)	Cost of cultivation (Rs/ha)	Net return (Rs/ha)	B:C ratio	Economic water productivity (Rs/mm)
Irrigation schedule						
Branching	1481	39.8*	29871	37339	1.25	1029*
Pod development	1543	42.4	29608	38915	1.29	1072
Branching + Pod development	1677	31.4	30572	46470	1.52	640
L.S.D (p=0.05)	140	-	-	3794	-	-
Crop establishment method						
Flat	1562	32.8	30028	41139	1.37	842
Raised bed	1572	40.7	30356	40678	1.34	1025
L.S.D (p=0.05)	NS	-	-	NS	-	-
Irrigation method						
Flood	1533	30.2	29541	40715	1.36	783
Sprinkler	1601	45.0	30446	41101	1.35	1233
L.S.D (p=0.05)	NS	-	-	NS	-	-

*Irrigation water productivity and economic water productivity for the irrigation scheduled at branching stage is given in the form of a mean of two years as in the first year of the study there was no irrigation applied because rainfall coincided with the irrigation period

Table 5. Energy use parameters as affected by irrigation schedules, establishment methods and irrigation methods

Treatment	Input energy (MJ/ha)	Output energy (MJ/ha)	Energy use efficiency	Specific energy (MJ/Kg)	Net energy gain (MJ/ha)
Irrigation schedule					
Branching	10695	21771	2.04	7.22	11076
Pod development	10695	22682	2.12	6.93	11987
Branching + Pod development	14426	24652	1.71	8.60	10226
L.S.D (p=0.05)	-	2,212	0.19	0.78	NS
Crop establishment Method					
Flat	13109	22961	1.75	8.39	9852
Raised bed	10768	23108	2.15	6.85	12340
L.S.D (p=0.05)	-	NS	0.153	0.64	1806
Irrigation method					
Flood	13528	22535	1.67	8.82	9007
Sprinkler	10349	23535	2.27	6.46	13186
L.S.D (p=0.05)	-	NS	0.153	0.64	1806

lower than flood irrigated crops. Although additional 94 MJ/ha energy was required for installation of the micro sprinkler set up but flood method required about 51.1 and 10% more energy than the sprinkler under flat and raised bed conditions, respectively (Fig. 2).

Output energy: The highest output energy (24652 MJ/ha) was obtained with irrigation provided at both branching and pod development stages of crop growth. It was significantly higher where irrigation was provided only at vegetative stage of crop growth (21,771 MJ/ha). Output energy did not vary significantly with establishment methods and irrigation methods.

Energy use efficiency: Among irrigation scheduling the highest energy use efficiency was obtained for the treatment when irrigation was given only at pod development stage (2.12) and was significantly higher than irrigation scheduling at both stages (1.71). Energy use efficiency significantly varied for establishment and irrigation methods. Between establishment methods, the higher energy use efficiency was obtained for the raised bed method (2.15) as compared to flat bed method (1.75). The higher energy use efficiency was obtained with sprinkler method (2.27) than flood method (1.67). Despite of higher yield in irrigation scheduled at both stages of crop growth the higher energy use efficiency in the irrigation provided either at vegetative or pod development stage treatment might be due to less input energy required in these methods. Similarly, raised bed method and sprinkler method of irrigation had more energy use efficiency than flat and flood method, respectively due to less energy consumption.

Specific energy: Among irrigation schedules, the highest specific energy (8.6 MJ/kg) was for the treatment where irrigation was provided at both stages of crop growth. Specific energy of the other two methods did not vary significantly with each other. Significantly higher specific energy was in flat method of establishment (8.39 MJ/kg) and flood irrigation (8.82 MJ/kg) in establishment and irrigation methods respectively.

Net energy gain: Irrigation schedules were statistically at par for net energy. Statistically, higher net energy was observed for raised bed method (12,340 MJ/ha) and sprinkler method (13,186 MJ/ha) among treatments belonging to land forms and irrigation methods respectively. Lesser input energy consumption in raised bed method and sprinkler irrigation as compared to flat bed method and flood irrigation, respectively resulted in significantly higher net energy in both the treatments.

CONCLUSION

Scheduling of irrigation in chickpea at both branching and pod development stage is required to obtain the higher net return and B: C. However, skipping irrigation at branching can provide comparable yield with almost half amount of water use and improves irrigation water productivity. Formation of raised bed and use of micro-sprinkler do not bring yield advantage or improvement in net return but save the considerable amount of water in chickpea production. Irrigation scheduling only at branching or pod development stage, growing of chickpea in raised bed and use of micro-sprinkler for irrigation can be adopted for energy saving in chickpea production.

AUTHORS CONTRIBUTION

Dr. Gurvinder Singh: Planning and execution of the

experiment at field level, writing. Rupanjali Baurai: Recording of observations. Mohini Singh: Data analysis. Sambita Bhattacharyya: Writing and editing

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Seasonal Incidence of Insect Fauna Associate with Rice Ecosystem

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***Abstract*:** Experiment was carried out at ICAR-National Rice Research Institute Cuttack, Odishato observe the insect fauna associated with the *kharif* rice ecosystem. Rice crop provide shelter to a number of insect species. The harmful species mainly belong to insect order of Lepidoptera (stem borer, leaf folder) and Hemiptera (plant hopper, gundhi bug) whereas the beneficial one includes several species of dragonflies, damselflies, predatory bug, predatory beetle and spider, a non-insect arthropod species. The incidence of harmful species was observed starting from August to November. The duration of sunshine hours plays an important and significant role in the incidence of yellow stem borer whereas maximum temperature plays a prime role in the incidence of leaf folder and plant hopper population. Minimum temperature and rainfall were negatively and significantly correlated with the population fluctuation of gundhi bug. The populations of predatory fauna such as dragonflies, damselflies, predatory bug, predatory beetle as well as spider fluctuate over a mean value throughout the cropping season. The population of dragonflies and damselflies were known to be more prevalent during the early growth period of the crop whereas the population of predatory bug and beetle were known to be more prevalent during the later period of growth. Spider populations were constant throughout the cropping season.The incidence of adult moth of yellow stem borer started at the end of August which reaches its peak during the third week of October. Similarly, the incidence of leaf folder started during the first week of August with its peak during the second week of September. The incidence of the hopper population started during the second week of August. The population of brown plant hopper was maximum during the third week of September as compared to that of green leaf hopper which reaches maximum during the beginning of October. The incidence of gundhi bug started during the second week of October as the crop enters into the reproductive stage and continued up to the harvesting of the crop.

Keywords: Yellow stem borer, Leaf folder, Plant hopper, Gundhi bug, Dragonflies, Damselflies, Spider

Rice (*Oryza sativa* L.) is one of the most important and widely cultivated crops throughout the world (Mohanta et al 2020) and occupies a pivotal place in Indian agriculture as a source of livelihood for about two-third of rural households. In India, paddy was grown under widely varying conditions of altitude and climate, extends from 8 to 35^0 N latitude and as high as 3000 meters from mean sea level. In India, paddy occupies an area of 41.1 mha with a production of 106.31 mt (Anonymous 2023). Among the several limiting factors,insect pests are the major biotic constraints in the production of the rice throughout the region (Mohapatra et al 2022). The rice plant is liable to attack by more than 100 species of insects and 20 of them can cause economic damage all over the world causing 30 % yield loss from seedling to maturity (Mohanta et al 2020). These includes yellow stem borer *(Scirpophaga incertulas),* leaf folder *(Cnaphalocrocis medanalis),* gall midge *(Orseolia oryzae),*brown plant hopper *(Nilpravata lugens),*green leaf hopper *(Nephotettix nigropictus Nephotettix nigropictus),* gundhi bug *(Leptocorisa acuta)* and case worm *(Nymphula depunctalis)* (Mohanta et al 2020, Sharma and Nayak 2005). Yellow stem borer is considered as a major pest in South East Asia (Giri et al 2022). There are several beneficial species that are always associated with the rice ecosystem. Some of them are dragonflies, damselflies, predatory bug, predatory beetle etc. Spider is one of the most abundant beneficial arthropod species associated with each and every rice ecosystem. The relationship between weather parameters and the population dynamics of the insect pests and their natural enemies may be a strong basis to know the status of pest occurrence with a time of incidence along with population level. This will help in pest forecasting as well as to take proper decisions regarding the management of insect pests.

MATERIAL AND METHODS

The experiment was conducted at ICAR-National Rice Research Institute, Cuttack, Odisha which is situated at 20° N latitude 86° E longitude and is at an elevation of 23.5 m above the mean sea level (MSL) during *kharif*2018-19.. The nursery was raised in the first week of July and 25-30 days old seedlings were transplanted in an area of 30 x 20 m^2 during the last week of July at a distance of 20 x 15 cm^2. All the

recommended agronomic practices were followed to raise the healthy crop except the plant protection measures required to manage the insect-pest for assessment of yield losses in protected plots. The population of insect pest (yellow stem borer, leaf folder, brown plant hopper, green plant hopper, gundhi bug) as well as their natural enemies (dragonfly, damselfly, predatory bug, predatory beetle and spider) were regularly monitored from seedling stage to harvesting at a weekly interval

Yellow stem borer: The population of YSB moth was monitored by using light trap as well as pheromone trap whereas the population of the larva was recorded in terms of % dead hearts and white ear heads at vegetative and reproductive stage, respectively. Light trap was installed with 200 W electric bulb at a height of 1.5 m from a ground-level near the paddy field. It was operated every night between 6 pm to 6 am. Daily catches of *stem borer* moths were recorded on the next day and data were collected and documented as weekly frequency of moth capture during the study period. Similarly, the pheromone traps (funnel traps) with scripolure were installed 200 m away from the source of light. Ten traps were placed in different locations at a distance of 300 m away from each other with in the research station. The traps were placed at 30 m above the crop canopy. Each trap contained one lure tube which was impregnated with a mixture of (Z)- 11 hexadecenal and (Z)-9 hexadecenal in a 3:1 ratio. The scripolure was changed at every 15 days interval after the first installation which was done after 15 days of transplanting of rice. The weekly trap catches of *S. incertulas* were recorded. Dead heart or white ear heads/10 hills during respective meteorological weeks of the season were also recorded to determine the correlation with abiotic factors.

Leaf folder: The observation regarding the leaf folder was taken by counting the number of larvae present in five plant and expressed as no. of larvae per plant.

Brown plant hopper and green leaf hopper: The number of adult and nymph were counted from five hills and expressed as number per plant.

Gundhi bug: The observation regarding gundi bug was taken by counting the number of adult and nymph from 5 sweep and expressed as number caught per sweep net.

Predatory arthropods: The population of predatory arthropods such as dragonflies, damselflies, and spiders was taken in one-meter square area whereas the population of predatory bug, predatory beetle was taken from the light trap at a weekly interval.

RESULTS AND DISCUSSION

Regular monitoring was carried out throughout the cropping season starting from the sowing of seed in the nursery to harvesting at a weekly interval (Table 1 and 2).

Yellow stem borer: During the season, the incidence of this pest was started during the 34th SMW (Aug 19-25) and continued up to the last week of November (Nov 26-Dec 2). In light trap, the maximum number of moths (10.26 per trap) was during the 43 SMW (Oct 21-27) whereas in pheromone

Table 1. Pearson correlation co-efficient between weather parameters and insect fauna associated with rice ecosystem

Weather parameters / Insect		T_{Max} (ºc)	T_{Min} (ºc)	RF (mm)	RH – I (%)	RH-II (%)	Wind (kmph)	Eva (mm)	SS Hrs	R^2
Yellow stem borer	LT	0.10	-0.13	-0.08	-0.18	-0.58**	-0.03	0.09	0.56**	0.54
	PT	0.03	-0.17	-0.15	-0.21	-0.54**	0.19	0.05	0.55**	0.61
	DH	0.45*	0.22	0.27	-0.04	-0.35	-0.52**	0.45*	0.32	0.64
	WEH	-0.24	-0.48*	-0.29	-0.13	-0.48*	0.19	-0.34	0.38	0.43
Leaf folder		0.54**	0.24	0.33	-0.12	-0.29	-0.64**	0.55**	0.24	0.79
Brown plant hopper		0.53**	0.27	0.27	-0.08	-0.20	-0.76**	0.53*	0.20	0.77
Green leaf hopper		0.49*	0.21	0.29	-0.04	-0.41*	-0.48*	0.45*	0.37	0.66
Gundhi bug		-0.38	-0.52**	-0.42*	-0.34	-0.37	0.25	-0.30	0.38	0.54
Dragon fly		0.33	0.86**	0.33	0.47**	0.77**	-0.06	0.30	-0.37	0.92
Damsel fly		0.39	0.79**	0.51**	0.36	0.70**	-0.19	0.42*	-0.30	0.92
Predatory bug		0.54**	0.45**	-0.07	0.34	0.20	-0.16	0.53**	0.17	0.45
Predatory beetle		0.31	0.46*	0.42*	-0.09	0.23	-0.50**	0.44*	0.01	0.64
Spider		0.36	0.09	0.10	-0.05	-0.47**	-0.20	0.37	0.66**	0.77

*. Correlation is significant at the 0.05 level , **. Correlation is significant at the 0.01 level.
YSB: Yellow stem borer, LT: Moth captured in light trap, PT: Moth captured in pheromone trap, DH: Dead heart, WEH: White earhead, LF: Leaf folder, BPH: Brown plant hopper, GLH: Green leaf hopper, GB: Gundhi bug
Tmax: Maximum temperature, T min: Minimum temperature, RF: Rainfall, RH-I: Morning relative humidity, RH-II: Evening relative humidity, Eva: Evaporation, SS Hrs: Sunshine hours

trap maximum number of moth (6.71 per trap) was during the 44th SMW (Oct 28-Nov 3). The formation of dead hearts was started from the 35th SMW whereas the formation of white ear heads was observed during the 41st SMW as the crop entered into the reproductive phase. Maximum dead heart per 10 hills was during 40th SMW with weather parameters of 34.60°C maximum temperature, 24.76°C minimum temperature, 90.71 % morning RH, 61.57 % evening RH, wind speed of 2.03 km/hand week, 6.06 hour of sunshine per day. The white ear head was maximum during the 46th SMW with weather parameters of 30.5°C maximum temperature, 18.5°C minimum temperature, 92.29 % morning RH, 66.29 % evening RH and wind speed of 2.17 km/h. However, during this week, there was no rainfall with 4.16 hour of sunshine per day. Joshi et al (2009) also observed the peak population of yellow stem borer during the third week of October indicating that population builds up late in the season at Hissar.

Leaf folder: During the season, the incidence of leaf folder was started from the 33rd SMW (Aug 12-18) as 0.73 larvae per hill and continued up to 45th (Nov 4-Nov 10). At the time of initial infestation, maximum and minimum temperatures prevailed were 31.4°C and 23.8°C, respectively with 13.86 mm rainfall and 2.59 hour of sunshine, the wind speed was 1.83 km/h with 94.57 % morning and 81.57 % evening RH. Thereafter, the population was increased at a steady rate and reached to peak (3.73 larvae per hill) during 40th SMW (Sep 30- Oct 6) with weather parameters of 34.60°C maximum temperature, 24.76°C minimum temperature, 90.71 % morning RH, 61.57 % evening RH, and wind speed of 2.03 kmph. Thereafter, a decline in the pest population was observed. Alvi *et al*. (2003) reported similar results that activity of *C. medinalis* lasted from second week of August to the third week of October at Punjab-Lahore whereas Hafeez et al. (2010) reported peak larval population during the first week of October under Varanasi conditions.

Brown planthopper: The incidence of BPH was started from the 33rd SMW (Aug 12-18) as 2.53 numbers of adult and nymph per hill and continued up to 44th (Oct 28- Nov 30). At the time of initial infestation, maximum and minimum temperatures prevailed were 31.4 °C and 23.8°C respectively with 13.86 mm rainfall and 2.59 hour of sunshine, the wind speed was 1.83 km/h with 94.57 % morning and 81.57 per cent evening RH. Thereafter, the population was increased at a steady rate and reached to peak (13.40 adult and nymph per hill) during 39th SMW (Sep 23-29) with weather parameters of 33.7°C maximum temperature, 23.7°C minimum temperature, 92.43 % morning RH, 69.43 per cent evening RH, 5.86 mm rainfall, 5.13 hours sunshine and wind speed of 0.86 km/h. Thereafter, there was observed a downfall in the pest population. Firake et al. (2010) also observed that,the most favorable period for brown plant hopper was from last week of August up to last week of September under Pantnagar conditions.

Green leaf hopper: The incidence of GLH was started during the 33rd SMW (Aug 12-18) as 1.00 numbers of adult and

Table 2. Regression equations between weather parameters and insect fauna associated with rice ecosystems

Y= Moth captured in light trap	$y = 26.23 - 0.38 X_1 + 0.31 X_2 + 0.05 X_3 - 0.2 X_4 - 0.13 X_5 + 1.66 X_6 + 0.54 X_7 + 0.97 X_8$	0.54
Y= Moth captured in pheromone trap	$y = 41.31 - 0.62 X_1 + 0.49 X_2 + 0.07 X_3 - 0.23 X_4 - 0.22 X_5 + 0.98 X_6 + 0.77 X_7 + 1.16 X_8$	0.61
Y= % dead heart formation	$y = 12.02 - 0.12 X_1 + 0.23 X_2 + 0.06 X_3 - 0.06 X_4 - 0.1 X_5 - 0.69 X_6 + 0.83 X_7 + 0.21 X_8$	0.64
Y= % white ear head formation	$y = 3.86 - 0.03 X_1 + 0.08 X_2 + 0.02 X_5 + 0.30 X_6 - 0.54 X_7 + 0.28 X_8$	0.43
Y= Number of larvae per hill	$y = 6.95 - 0.05 X_1 + 0.09 X_2 + 0.04 X_3 - 0.06 X_4 - 0.05 X_5 - 0.62 X_6 + 0.54 X_7 + 0.03 X_8$	0.79
Y= Number of nymph and adult per hill	$y = 20.07 - 0.19 X_1 + 0.32 X_2 + 0.07 X_3 - 0.16 X_4 - 0.15 X_5 - 3.63 X_6 + 1.42 X_7 - 0.10 X$	0.77
Y= Number of nymph and adult per hill	$y = 43.94 - 0.01 X_1 + 0.01 X_2 + 0.24 X_3 - 0.33 X_4 - 0.5 X_5 - 2.67 X_6 + 2.82 X_7 + 1.0 X_8$	0.66
Y= Number of nymph and adult per sweep net	$y = 34.44 - 0.62 X_1 + 0.01 X_2 - 0.05 X_3 - 0.14 X_4 - 0.04 X_5 + 0.73 X_6 - 0.11 X_7 + 0.66 X_8$	0.54
Y= Number of dragon flies per m^2 area	$y = -13.28 - 0.01 X_1 + 0.20 X_2 + 0.01 X_3 + 0.06 X_4 + 0.07 X_5 - 0.03 X_6 + 0.15 X_7 + 0.03 X_8$	0.92
Y= Number of damsel flies per m^2 area	$y = -19.00 - 0.12 X_1 + 0.07 X_2 + 0.07 X_3 + 0.04 X_4 + 0.11 X_5 + 0.04 X_6 + 0.47 X_7 + 0.30 X_8$	0.92
Y= Number of predatory bug captured in light trap	$y = -44.94 + 0.45 X_1 + 0.14 X_2 + 0.01 X_3 + 0.24 X_4 + 0.13 X_5 - 0.06 X_6 + 1.35 X_7 + 0.62 X_8$	0.45
Y= Number of predatory beetle captured in light trap	$y = 16.23 - 0.36 X_1 + 0.32 X_2 + 0.09 X_3 - 0.16 X_4 + 0.03 X_5 - 1.01 X_6 + 1.19 X_7 + 0.48 X_8$	0.64
Y= Number of spider per m^2 area	$y = 3.54 - 0.05 X_1 + 0.07 X_2 + 0.05 X_3 - 0.04 X_4 - 0.02 X_5 + 0.33 X_6 + 0.46 X_7 + 0.63 X_8$	0.77

X_1: Maximum Temperature (°C)
X_2: Minimum Temperature (°C)
X_3: Rainfall (mm)
X_4: Morning Humidity (%)
X_5: Evening Humidity (%)
X_6: Wind velocity (kmph)
X_7: Evaporation
X_8: Sunshine hours

nymph per hill and continued up to 45th SMW (Nov 4-Nov 10). At the time of initial infestation, maximum and minimum temperatures prevailed were 31.4°C and 23.8°C, respectively with 13.86 mm rainfall and 2.59 hour of sunshine; the wind speed was 1.83 km/h with 94.57 % morning and 81.57 per cent evening RH. Thereafter, the population was increased at a steady rate and reached to peak (24.73 adult and nymph per hill) during 40th SMW (Sep 30- Oct 6) with weather parameters of 34.6°C maximum temperature, 24.76°C minimum temperature, 90.7 per cent morning RH, 61.57 per cent evening RH, and wind speed of 2.03 km/h. However, during this week, there was no rainfall with 6.06 hour of sunshine per day. Thereafter, a decline in the pest population was observed. Choudhary et al (2014) also reported that, population of plant hoppers reaches its maximum during the first week of October at Varanasi.

Gundhi bug: The incidence of gundhi bug was started during the 41st SMW (Oct 7-13) as 0.40 numbers of adult and nymph per sweep and continued up to harvesting of the crop. At the time of initial infestation, maximum and minimum temperatures prevailed were 31.1°C and 21.9°C respectively with 39.71 mm rainfall and 1.71 hour of sunshine, the wind speed was 2.61 km/h with 90.71 % morning and 62.29 % evening RH. Thereafter, the population was increased at a steady rate and reached to peak (9.07 adult and nymph per sweep net) during 44th SMW (Oct 28- Nov 3) with weather parameters of 34.6°C maximum temperature, 24.7°C minimum temperature, 90.71 % morning RH, 61.57 % evening RH, and wind speed of 2.03 kmph. Thereafter, a decline in the pest population was observed. Kalita et al.(2015) also observed that the population of gundhi bug was found maximum when the crop attained the milky stage in the last week of October.

Predatory insects: During the period of study, several beneficial insects were found to be associated with rice ecosystems. Some of them were dragonflies, damselflies and several predatory bugs and beetle. The population of this insect fluctuateover mean value during the entire cropping season (Table 2). The population of dragonflies and damselflies varies from 0.33 to 4.33 and 0.33 to 4.67 respectively throughout the entire season. Similarly, the population of predatory bug ranges from 1.00 to 12.00 per

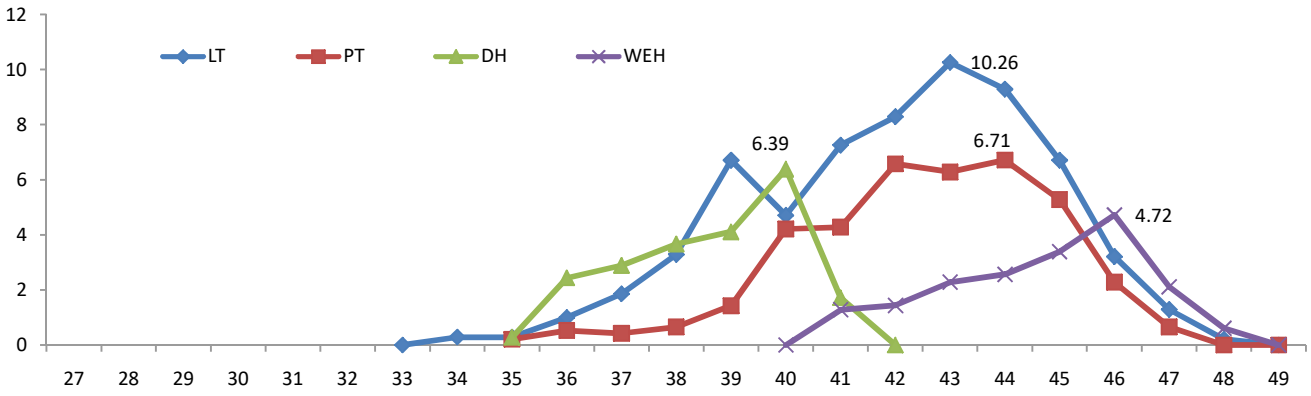

Fig. 1. Seasonal incidence of yellow stem borer (LT: Light trapped moth; PT: Pheromone trapped moth, DH: Dead Heart; WEH: White earhead) associated with rice ecosystem

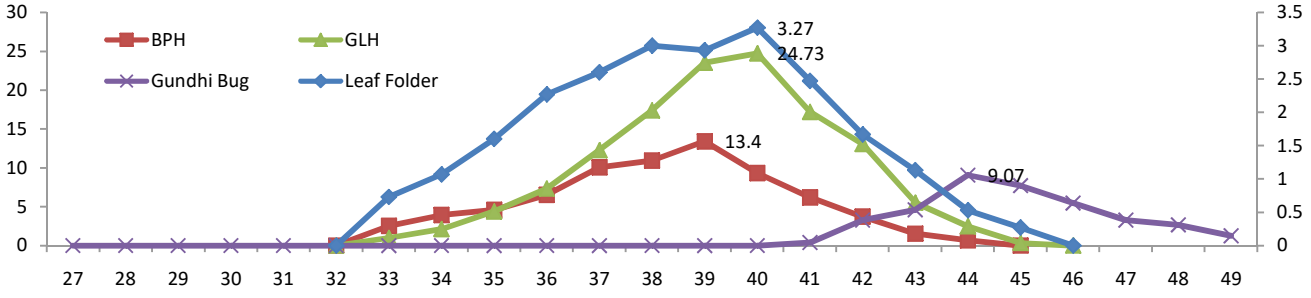

Fig. 2. Seasonal incidence of leaf folder (Number of larvae/plant), Brown plant hopper (BPH), Green leaf hopper (GLH) and Gundhibug associated with rice ecosystem

trap per week and that of predatory beetle ranges from 1.00 to 8.00 per trap per week. However, these above insects are more prevalent during the early growth period particularly from July to September because of cloudy weather and frequent rainfall. Their population tends to be decline during the month of October and November because of the decline of maximum temperature.

Spider: This non-insect arthropod is very common in rice ecosystems throughout the growing period and varied in their number and diversity. The number of spiders varied from 0.33 to 3.66 per m^2 area. They are known to be parasitized the egg as well as early instar nymph of various harmful insects associated with the crop.

Correlation coefficients and regression equations between population of insect fauna and different abiotic parameters indicate that the population of leaf folder (number of larvae per plant), brown plant hopper, green leaf hopper and predatory bug as well as per cent dead heart formation had a positive and significant correlation with maximum temperature whereas the population of dragonflies, damselflies, predatory bug and beetle had a positive and significant correlation with minimum temperature. The population of damselfly and predatory beetle had positive and significant relation with rainfall whereas that of gundhi bug was found negative and significant with the same. The population of yellow stem borer as well as per cent white ear head formation, population of green leaf hopper, dragonflies, damselflies and the spider had a negative and significant correlation with the evening relative whereas that of dragonflies had a positive and significant correlation with morning relative humidity. The population of major pests such as brown plant hopper, green leaf hopper, leaf folder, yellow stem borer (per cent dead heart formation) and predatory beetle had a negative and significant correlation with wind speedwhereas that of adult moth of yellow stem borer and the spider had a positive and significant correlation with duration of sunshine hours. The population of leaf folder, brown plant hopper, green plant hopper, damselflies, predatory bug and beetle as well as per cent dead heart formation had positively and significantly correlated with it. Mohanta et al (2020) also reported that leaf folder and brown plant hopper population had a positive and significant relation with maximum

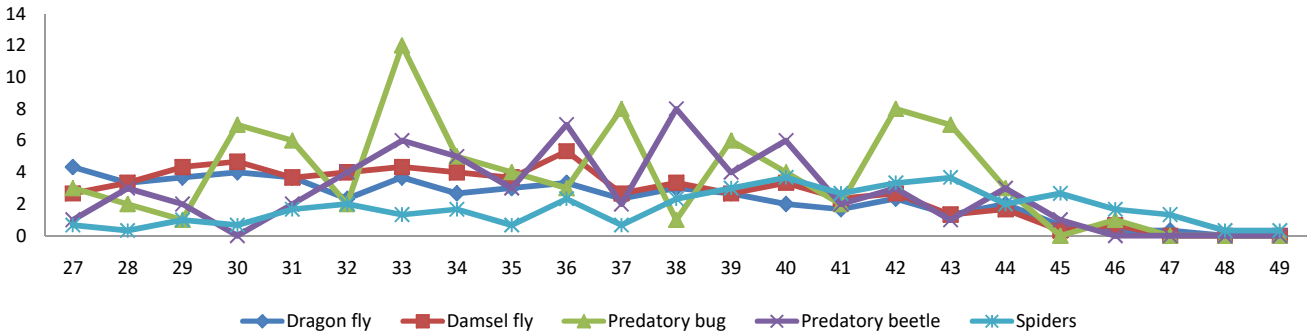

Fig. 3. Seasonal incidence of beneficial insect fauna and other arthropod species associated with rice ecosystem

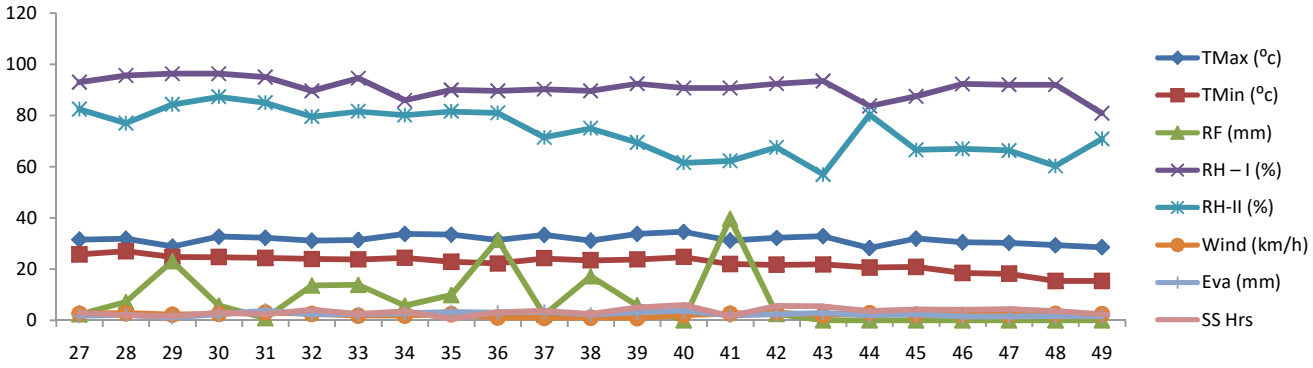

Fig. 4. Graphical representation of prevailing weather parameters during study period (Tmax: Maximun Temperature, T min: Minimum Temperature, RF: Rainfall, RH-I: Morning Relative Humidity, RH-II: Evening Relative Humidity, Eva: Evaporation, SS Hrs: Sunshine hours)

temperature whereas per cent white ear head formation and gundi bug population had a negative and significant relation with minimum temperature. Gundi bug, yellow stem borer and green leaf hopper had a negative and significant relation with rainfall and evening relative humidity, respectively.

CONCLUSION

The incidence of yellow stem borer, leaf folder and plant hopper were started during the month of August and continued up to the October. The formation of the dead heart reaches its maximum during the end of September whereas the formation of white ear head reaches its maximum during the first week of November. The population of brown plant hopper reaches its maximum earlier i.e during the third week of September as compared to that of green leaf hopper which reaches its maximum during the beginning of October. The incidence of gundhi bug started during the second week of October as the crop enters into the reproductive stage and continued up to the harvesting of the crop. During the period of investigation, it was found that the duration of sunshine hours plays an important and significant role in the incidence of yellow stem borer whereas maximum temperature plays a prime role in the incidence of leaf folder and plant hopper population.

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Population Dynamics of Mustard Aphid in Relation to Weather Parameters and Effect of Predators on Aphid Population

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***Abstract*:** The experiments were conducted to assess the population dynamics of mustard aphid (*Lipaphis erysimi*) and its important predators on three dates of sowing at Banda. The occurrence of mustard aphid was started from 52nd Standard Week (SW) and continued till harvest (12th SW). The population ranged from 0.15 to 26.31, 0.11 to 259.34 and 0.03 to 305.49 aphids/10 cm central twig/plant, respectively on timely, mid late and late sown crop. Four predators *viz*., *Coccinella septempunctata*, *Coccinella* spp. (unidentified), *Cheilomenes sexmaculata* and Syrphid fly (*Episyrphus balteatus*) were recorded at different stages of the crop growth. The population of predators was significantly increased with an increase in the aphid population from 7th to 10th SW among the different dates of sown crops. A mixed type of significant level of correlation coefficient had shown among mustard aphid and weather parameters and even the dates of sown crops. The multiple stepwise linear regression equations showed weather parameters greatly influenced the aphid population at timely and mid late sown mustard crops, however the aphid predators were more influenced at mid-late and late sown mustard crops and both abiotic and biotic factors played a vital role in growth multiplication, development and distribution of mustard aphid.

***Keywords*:** Population dynamics, *Lipaphis erysimi*, Predators, Correlation, Weather parameters

Rapeseed (*Brasssica rapa* L) is one of the major oilseed crops grown in Rabi season in India and ranks third in total acreage (19.8%) and production (9.8%) of the world (Anonymous 2019). However, its production and productivity are much influenced with the biotic and abiotic stresses. In case of biotic stresses, among 38 insects associated with *Brassica* at different stages of its growth, the mustard aphid, *Lipaphis erysimi* (Kaltenbach), continues to be the key pest damaging oilseed brass. It is the major limiting factor causing up to 96% yield losses from the seedling stage to maturity (Shylesha et al 2006) and a decrease of about 15% in oil contents. Both nymphs and adults suck the cell sap from different parts of the plant i.e., inflorescence, leaf, stem, twig and pods. Biotic factors, such as *Coccinella septempunctata* (Linnaeus), *C. transversalis* (F.) and *Harmonia axyridis* (F.), green lacewing, *Chrysoperla carnea* (Stephens); syrphid fly, *Xanthogramma scutellaris* (Fab.) are the major natural enemies on insect pests of mustard that directly inhibit the pest population. Among these, *C. septempunctata* and *C. transversalis* are considered as major dominating predators of aphids and range between 5 to 20 per cent predation in the field (Singh et al 2018). Abiotic parameters also play a vital role in the population build-up of mustard aphids. Their positive or negative association with the pest population gives a place to develop suitable management strategies against the pest. Repeatable and reliable management decisions can be made based on monitoring information. Therefore, considering the above fact, the present investigation was envisaged to information on the population dynamics of mustard aphid, its predators in relation to weather parameters in Bundelkhand region of Uttar Pradesh.

MATERIAL AND METHODS

The present investigation was conducted during 2019-20 and 2020-21 at Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India (24º 53′ 25º 55′ N latitude, 80º 07′ 81º 34′ E longitudes). The rapeseed variety BSH-1 was raised at three different dates *viz.,* timely sown (15th October), mid-late sown (05th November) & late sown (25th November) following recommended package of practices during *rabi* 2019-20 and 2020-21**.** Data were recorded on the population of mustard aphid and its natural predators on their natural host rapeseed by following standard sampling methodology given by Singh and Lal, (1999). Observations were recorded from 400 m^2 area for each date of sowing.

Mustard aphid: At initial stage population was quite low, thus count was made on leaves and shoots as well. After the stem elongation, populations were recorded at weekly intervals from 120 randomly selected plants with aphids counted from top 10 cm apical shoot (Singh and Lal 1999) from the time of appearance till harvest.

Predators: Observations on the population of predators was recorded at weekly interval by visual counting the total number of grubs and adult beetles / plant for coccinellids and total number of maggots /10 cm apical twig for syrphid fly separately on each date of sown crops.

Statistical analysis: For study the impact of weather parameters on the population build-up of mustard aphid and their natural predators, the meteorological data (weekly mean) on temperature (maximum and minimum), relative humidity (maximum and minimum), rainfall (mm) and wind speed (kmph) were obtained from meteorological observatory of the College of Agriculture, BUA&T, Banda for the experimentation period. Correlation coefficients were worked out for the population build-up (means of pooled data of two cropping seasons) of mustard aphid in relation to their predators and weather parameters. Further, step-wise linear regression model was developed for estimating alate aphid with the climatic parameters namely, temperature (maximum and minimum), relative humidity (maximum and minimum), rainfall (mm) and wind speed (kmph). The data were analyzed by using OPSTAT online software developed by CCSHAU, Hisar.

RESULTS AND DISCUSSION

Population build-up of mustard aphid and their predators: The evident of the pooled mean data that mustard aphid first appeared in the last week of December (52nd SW) on all three dates of sown crop and continued till harvest of the respective date of sown crop (Table 1, Fig. 1). The population attained its peak in 7th SW on timely and mid-late sown crops, where the aphid population was 14.19 and 158.25 aphids/10 cm top apical terminal shoot, respectively, however on late sown crop the peak was observed in 8th SW where the population was reached up to 222.19 aphids/10 cm top apical terminal shoot. Mehnaj et al (2017) also observed the appearance of mustard aphid and its peak activity in 51st SM and 8th SW, respectively. Similarly, the peak activity of mustard aphids between 6th to 8th SW recorded by Singh et al (2018). Meena et al (2019) also recorded comparatively lower incidences of aphid population on crops sown by mid-October, whereas in mid-late and late sown crops, significantly higher numbers of aphid's infestation were observed by Srivastava and Prajapati, 2012. Observations on the natural predators revealed that the prevalence of two groups of predators *viz*., coccinellids beetles (*Coccinella septempunctata*, *C. transversalis* and *Cheilomenes sexmaculata*) and Syrphid fly (*Episyrphus balteatus*) (Table 1). Among the date of sown crops, comparatively higher population of coccinellids and syrphid fly were recorded on the crop sown by 25th November (late sown). The population of predators have significantly increased with an increase in the aphid population. Mishra and Kanwat (2018) also observed high larval populations of predators coincided with peaks in the aphid population. The trend of the occurrence of the predators in present study conformity with Dwivedi et al (2018), where peak activity of coccinellids and shyrphids between 6th to 12th SW.

Correlation between aphid population and their predators: The population of both the predators (coccinellids and shyrphids) had positive correlation with mustard aphid in all the date of sown crops (Table 2). The population of coccinellid had a significant correlation in timely sown and highly significant correlation in late sown. Whereas, the population shyrphid fly had a significant correlation in timely sown and highly significant correlation in mid-late and late sown crops with mustard aphid. It is clear that, the population of predators increased gradually with an increase of aphid population and then resulting in gradual decrease in aphid population. Singh et al (2018), also reported that mustard aphid, *L. erysimi* were showed a high positive correlation with predators. In present study the peak activity of predators occurred in later crop stage, when the aphid population was maximum in the field. The peak activity syrphids was recorded in 8th and 9th SW and then gradually decreased with decrease in aphid population revealing a positive correlation between population of aphid and syrphids. The syrphids play a positive role in reduction of aphid population in the field. Similar results were also observed by Devi et al (2011).

Correlation between population of mustard aphid and abiotic factors: The minimum temperature and rainfall had non-significant correlation on all the dates of sown crop, whereas maximum temperature had significant positive correlation with mustard aphid only on the mustard crop sown

Table 2. Correlation(r) coefficient of aphid with their predators and weather parameters

Sowing time	Coccinellids	Syrphids	Temperature (°C)		Relative humidity (%)		Wind speed (kmph)	Rainfall (mm)
			Minimum	Maximum	Minimum	Maximum		
Timely	0.661*	0.571*	-0.060	0.134	-0.033	-0.024	-0.829**	0.200
Mid late	0.528	0.756**	0.083	0.341	-0.191	0.181	-0.697*	-0.006
Late	0.766**	0.892**	0.453	0.612*	-0.587*	-0.566*	0.039	0.024

** Highly significant at 1% level of significance; *Significant at 5% level of significance

by 15th November (Table 2). Similarly, minimum and maximum relative humidity both had nonsignificant correlation on timely and mid-late sown crops but a significant negative correlation with mustard aphid at late sown crops. The population of mustard aphid showed a highly significantly negatively correlation in timely sown, a significant negative correlation at mid-late sown and nonsignificant positive correlation on late sown crop with wind speed. A positive correlation with temperature and significant negative correlation with relative humidity have also observed by Zia and Haseeb (2019). Srivastava and Prajapati (2012) also observed the significant relation with temperature on late sown crop, negative as well as positive association with relative humidity and negative nonsignificant correlation with rainfall in their study at Bundelkhand of Madhya Pradesh. There was mixed type correlation among the different dates of sown crops and is in partial agreement with the results of Ali and Rizvi (2012)

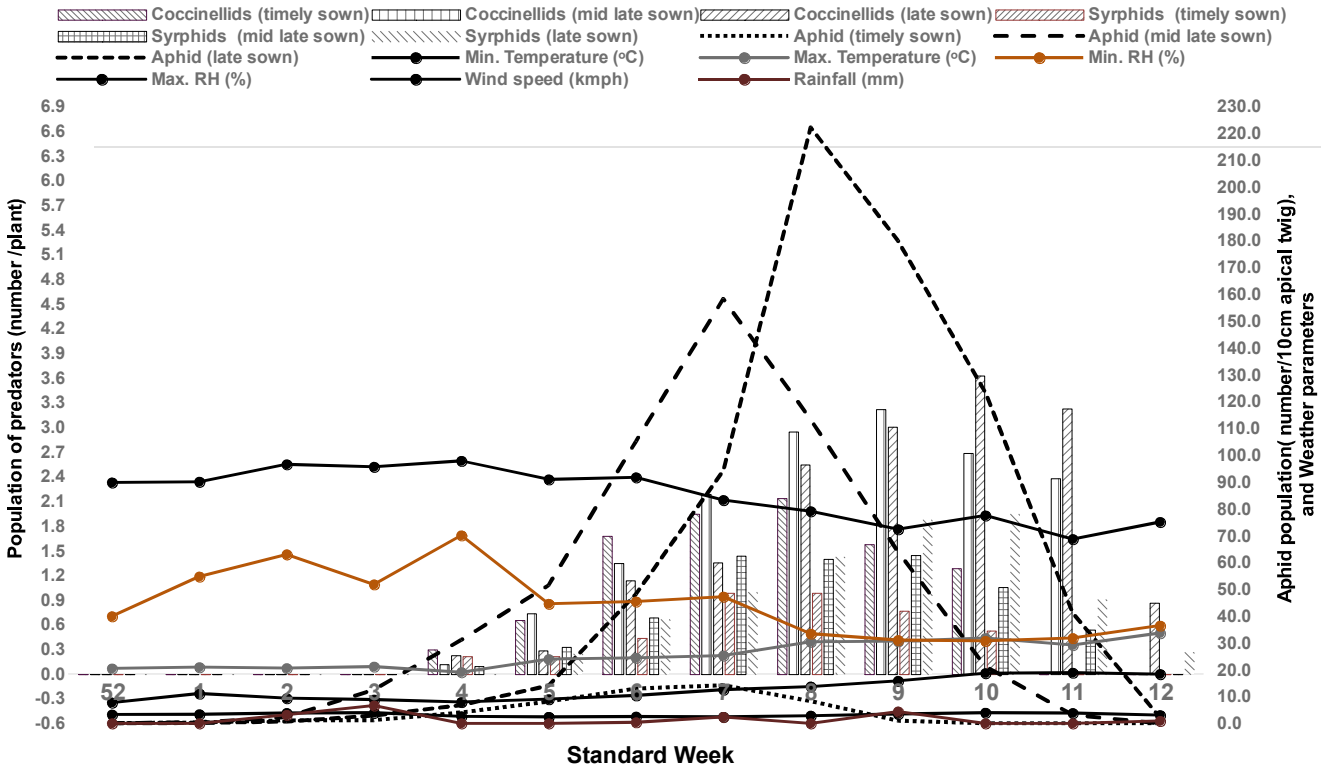

Fig. 1. Relation of mustard aphid (*Lipaphis erysimi*) with their predators and weather parameters.

Table 3. Stepwise regression equations for estimating the influence of weather parameters on the incidence of alate mustard aphid during 2019-21 (Pooled)

Particulars	Sowing dates	Regression equation	R^2
Aphid population	Timely sown	$Y= -27.58 + 1.43*T_{Min.} -0.02*T_{Max.} -0.20*RH_{Min.} + 0.67*RH_{Max.} -10.10*WS + 0.10*RF$	0.89
		$Y= -9.13 -1.75*T_{Min.} + 1.38*T_{Max.}$	0.23
	Mid late sown	$Y= 0.43 + 7.32*T_{Min.} + 3.76*T_{Max.} -0.42*RH_{Min.} + 1.98*RH_{Max.} -94.22*WS + 11.41*RF$	0.87
		$Y= -161.93 -15.24*T_{Min.} + 15.79*T_{Max.}$	0.37
	Late sown	$Y= 378.18 -27.97*T_{Min.} + 20.78*T_{Max.} +1.73*RH_{Min.} -7.54* RH_{Max.} +19.58*WS+ 0.72*RF$	0.52
		$Y= -261.19 -11.95*T_{Min.} + 18.33*T_{Max.}$	0.45
Predators population	Timely sown	$Y= 1.08 + 8.42*X_1 -9.99*X_2$	0.48
	Mid late sown	$Y= 15.74 -56.26*X_1 + 179.15*X_2$	0.81
	Late sown	$Y= 0.88 -27.39*X_1 + 140*X_2$	0.83

Note: $T_{Min.}$= Minimum Temperature (oC); $T_{Max.}$= Maximum temperature (oC); $RH_{Min.}$= Minimum RH (%); RH_{Max}= Maximum RH (%) and WS= Wind Speed (kmph); RF= Rainfall (mm), X_1= Coccinellids and X_2=Syrphid

where a variability in correlation between *L. erysimi* population and whether parameters among three dates of sown crop was observed.

Regression analysis: Based on pooled data of two cropping seasons, the combined influence of all the weather parameters had more influence on population fluctuation of mustard aphid as R^2 value was 0.89, 0.87 and 0.52 (Table 3). Das et al (2019) also observed weather parameters contributed 72- 87% variation in aphid population. Mandal et al (2018) also reported the combined effect of temperature, light intensity and relative humidity depicted 81.7 per cent abundance of *L. erysimi*. The R^2 value of temperature (minimum & maximum) only were 0.23, 0.37 and 0.45 at timely, mid late and late sown crops, respectively. Soni et al (2021) also observed maximum, minimum temperature and sunshine hours contributed only 41 per cent variation in aphid population and was depicted in predictive model. In case of predators, it was evident from the data that predators influenced with aphid population significantly at mid-late and late sown crops and contributed to the extent of 81 and 83 per cent, respectively, as compared to timely sown crops, where variation was 48 per cent. It is evident from the stepwise regression equations that weather parameters greatly influenced the aphid population at timely and mid late sown mustard crops, however, the predators were more influenced at mid-late and late sown mustard crops and both abiotic and biotic factors played a vital role in growth multiplication, development and distribution of mustard aphid.

AUTHORS CONTRIBUTION

AK conducted experiments and collect the data from field. MKM devised and designed, supervised the research and wrote the manuscript, RP writing-review and edited the manuscript, AKS worked out data curation and formal analysis, BKS and SKS were provided the facilities and edited the manuscript. All the authors read and approved the manuscript.

CONCLUSIONS

The population of mustard aphid *L. erysimi* was quite low at timely sown crops by 15th October as compared to mid-late (05th November) and late sown (25th November) mustard crop in Bundelkhand region of Uttar Pradesh. Among weather parameters, maximum temperature, relative humidity (minimum & maximum) exhibited significant correlation with *L. erysimi* only at late sown crop. Coccinellids and syrphid fly both exhibited strong positive correlation with mustard aphid population at variable dates of sown crops. The multiple linear regression analysis showed that the weather factors and predators both played a vital role in growth multiplication, development and distribution of mustard aphid. Based on the present study sowing of mustard crops up to the third week of October is the best time to avoid the aphid infestation.

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Performance Characterization of Spray Nozzles Based on CFD Simulation

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***Abstract*:** Computational Fluid Dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems related to fluid flow. The study conducted a comprehensive analysis of the design and operational parameters of plant protection equipment, with a focus on factors such as operating pressure, height, nozzle type, fluid density, and viscosity. The investigation utilized Computational Fluid Dynamics (CFD) and the ANSYS FLUENT software to simulate the behavior of lime juice and distilled water mixtures across various proportions. Both hollow cone and flat fan assemblies exhibited increased discharge rates (0.223 to 0.254 L/min for flat fan, 0.222 to 0.359 L/min for hollow cone) and wider swath widths (372 to 558 mm for hollow cone, 254 to 385 mm for flat fan) as pressure increased from 1.5 to 2.5 kg/cm^2. Droplet size decreased with pressure for flat fan (284-263 microns) and hollow cone (336-278 microns), while spray angles increased 50 to 69^0 for hollow cone and 35 to 51^0 for flat fan with pressure 0 .5 to 2.5 kg/cm^2 and height of 400 to 500 mm. The results emphasize the need to balance environmental impact and biological efficacy in optimizing plant protection equipment performance.

Keywords: ANSYS FLUENT, CFD, Hallow cone, Flat fan

India is the fifth-largest global producer of agrochemicals and fourth largest exporter after United States, Japan and China, with the industry ranking 13th in Asia. The global pesticide consumption in 2019 was approximately 4.19 million metric tons, where China was by far the largest pesticide-consuming country (1.76 million metric tons), followed by the United States (408 thousand tons), Brazil (377 thousand tons), and Argentina (204 thousand tons) (Fernández 2021). The per hectare consumption of pesticides in India is amongst the lowest in the world and stands at 0.6 kg/ha against 5-7 kg/ha in the United Kingdom and 13 kg/ha in China (Pushpendra and Nitish Rattan 2018). Paddy accounts for 26-28% of agrochemicals, followed by cotton (18-20%). The states Maharashtra, Punjab, Uttar Pradesh, Telengana, Haryana and West Bengal, account for over 70% of agrochemicals used in India (FCCI 2021).

Pest management is crucial to reduce economic damage caused by pests, and various pest control methods include chemical, biological, mechanical, physical, legal, and cultural approaches. Chemical control is the only method for controlling pests, insects, and weeds, and can be applied through spraying or dusting. Droplet size is an important factor affecting drift, as good coverage is essential for agrochemical that comes into contact with disease-causing organisms. Fine- to medium-sized droplets are preferred for insecticides and fungicides due to better coverage. The distribution of spray coverage and deposition on the crop surface depends on factors such as droplet size, droplet density, Physio-chemical properties of spray liquid, crop surface characteristics, and meteorological conditions. Computational Fluid Dynamics (CFD) modelling can help overcome these challenges and provide more robust and accurate results.

MATERIAL AND METHODS

Liquid properties: In this study a mixture of organic lime juice and distilled water in different proportions was used. Six samples have been used with ambient temperature at 22ºC. The sample is pure organic lime juice (L100) water (W0), L10 is 10% of organic citric acid mixed with 90% water, L20, L30 and, L40, L50 to determine viscosity and density of liquid.

Density of a lime juice: The Pycnometer is cleaned, dried, and weight is determined (w_1). A specific gravity bottle is filled with distilled water (w_2), and the temperature of the mixture is. The weight is recorded (w_3) and cleaned.

$$\rho = \frac{m}{v}$$

Where-ρ= density in gm/ml, m= mass (gm), v=volume (ml)

The density of lime juice (ρ_2) = mass of liquid / mass of equal volume of distilled water

$$\frac{\rho 2}{\rho 1} = \frac{W3 - W1}{W2 - W1}$$

The density of distilled water at room temperature is ρ_1 0.997 gm/ml standard.

Viscosity of lime juice: The Ostwald viscometer method is used to measure the viscosity coefficient based on Poiseuille's law. The rate of flow of liquid through a capillary tube with viscosity coefficient, η, can be expressed as

$$\eta = \frac{\pi p r^4}{8vl}$$

Where, v= vol. of liquid (in ml), t= flow time (in sec.) through capillary

r= radius of the capillary (in cm), l= length of the capillary (in cm)

P= hydrostatic pressure (in dyne/sq.cm), η = viscosity coefficient (in poise)

The hydrostatic pressure of a liquid is determined by P = ρgh, where h is the column height and ρ is the liquid's density. The viscosity coefficients η1 and η2 are used to study the liquids' densities and flow times through the same capillary.

$$\frac{\eta 1}{\eta 2} = \frac{\rho 1 t 1}{\rho 2 t 2}$$

The process involves creating various water-lime juice mixtures, filling a viscometer with the mixture, sucking it through a capillary tube, and recording the time of flows. The viscosity of distilled water at 20°C is 1.0020 cP.

Dimensional modelling of existing self-propelled intra canopy boom sprayer: The self-propelled intra boom sprayer was designed using Solid Works 2016 to understand fluid flow dynamics from the spray tank to nozzles (Fig. 1). The model includes components like flat fan and hollow cone nozzles, which were analysed using ANSYS work. Cylindrical spray tank with capacity of 118 litres with height of 600mm and a diameter of 500mm was used as a reservoir for chemical solution during spraying. The nozzles are used for specific insecticide and herbicide applications, with fan angles of 65°, 80°, and 110°. In current study flat fan nozzle TP8001VK and a hollow cone tip, TXA8002VK (Fig. 2) which were converted to 3-Dimension models and attached to the sprayer boom at 50cm spacing were used as shown in (Fig. 3).

The detailed front and side views of the model are provided.

Description of computational fluid dynamics in fluid flow simulation: Computational Fluid Dynamics (CFD) is a crucial tool in engineering design and analysis, particularly for thermal applications. Its key requirement is the ability to simulate flows along nozzles, which can be challenging due to features like eddy location, is more accurate than empirical methods used in design. Accurate simulation of flow through the nozzle is essential for predicting pressure and velocity patterns. CFD deals with the dynamic behavior of fluids and is governed by partial differential equations, which are often difficult to obtain analytically. CFD provides qualitative and quantitative solutions for predicting fluid flows through numerical methods, mathematical modeling, and software tools like solvers, pre- and post-processing tools. It enables engineers and researchers to perform numerical experiments, such as CFD simulation. ANSYS workbench is a graphical user interface that allows users to use these tools from a single place, assessing pre-processor, solver, and post-processor tools.

CFD analysis by finite elemental method in ANSYS FLUENT14.0 Version: The steps were as follows

1. The tank and nozzle assembly model is evaluated using Solid Works 2016 design, and the research area employs ANSYS Workbench 14 version, which includes over 40 tools. The present of study area use ANSYS CFD FLUENT.
2. Double click the "Fluid flow FLUENT", Go to "Geometry" and right click "Import geometry" then Go to "Browse" and select the file modeled in solid works.
3. The text emphasizes the importance of proper geometry meshing in FEA Analysis, which is crucial for accurate results. The software solves each element for converging to a specific solution, with a higher number of elements resulting in better results.
4. The polygonal mesh is used for tank and nozzle assembly, and the model is divided into equal parts with 80118 nodes and 17324 elements**.**
5. **"**Name selection" Input is given as Tank; Output is given as nozzle tip i.e., hallow cone and flat fan nozzles at 400 mm, 500mm height.

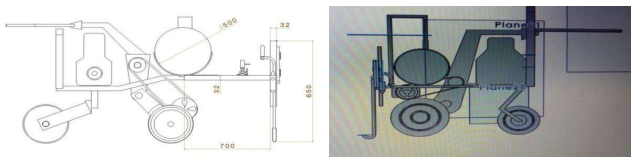

Fig. 1. Dimensions of the designed parts

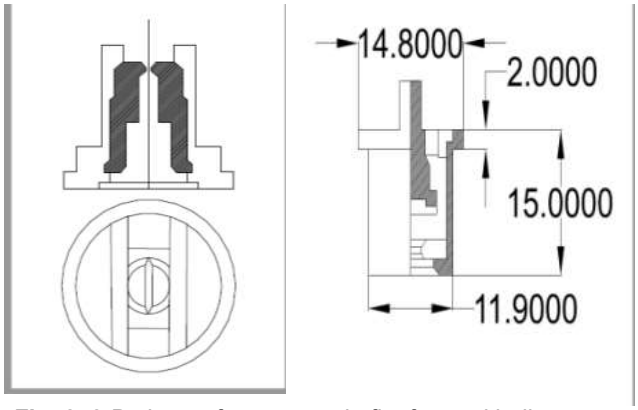

Fig. 2. 2-D views of spray nozzle flat fan and hollow cone

General settings of ANSYS CFD analysis: The Solver was taken as pressure based, time as steady and space as 3D. Velocity formulation as absolute, to analyze flow from tank to nozzle in ANSYS CFD, follow these steps: upload the model, select "General" option, click "pressure based" and "Absolute" under velocity, and select the standard k-ε turbulent model. This model provides results on pressure volume, velocity, eddy viscosity contours, discharge rate, swath, spray angle, and pressures for flat fan and hollow cone nozzles.

Standard K-Epsilon equation used in the ANSYS for the simulation of CFD: FLUENT's standard k-ε turbulent model is the default turbulence model, derived for flows with high Reynolds numbers. It solves a second transport equation for dissipation rate and is suitable for flows with nearly iso-tropic turbulence and local equilibrium energy cascade. This model was used for simulation of turbulent flow through a spray nozzle, based on kinetic energy (k) and dissipation rate (ε). Based on fully turbulent conditions, this model is reliable, accurate, and simple, with fast convergence, making it widely used for flow problem study.

Governing Equations for *k–ε* turbulent model: For turbulent kinetic energy *k*

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\varepsilon$$

For dissipation **ε**

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

Where u_i represents velocity component in corresponding direction

E_{ij} represents component of rate of deformation, μ_t represents eddy viscosity.

Where σ_k, $\sigma\varepsilon$, $C_{1\varepsilon}$ and $C_{2\varepsilon}$ are constants .The values have been arrived at by numerous iterations of data fitting for a wide range of turbulent flows. They are as follows:

C_μ=0.09 σ_k =1.00 σ_ε=1.30 $C_{1\varepsilon}$=1.44 $C_2\varepsilon$ =1.92

The eddy viscosity is μ_t computed by combining *k* and ε as follows:

$$\mu_t = \rho C_\mu k^2/\varepsilon$$

The material panel displays the default material as nitrogen, oxygen, and water. To create a simulation material, double click the mixture template. The solid Galvanized iron was used for tank, and properties were calculated in ANSYS work bench. The fluid was lime water (30%) and distilled water (70%), and the properties of the fluid were calculated. The model is then defined with set boundary conditions given (Table 1) and equation used for analysis.

Click on "Solution" Initialize the "Hybrid initialization". Write the number of iterations and then click "Run calculation". We have given 10 iteration values in the initialization of solution and it is a scalar “0” and scalar “1” value ranging from 1.00000e+00 to 499987e+00. Results can be obtained from the graphic display and report in FLUENT. Results can be displayed in terms of contour, velocity vector, viscosity, eddy viscosity, pressure, volume rendering, and eddy viscosity rendering in the tank and nozzles.

Experimental parameters: This is given in Table 2.

Spray angle and swath width: The spray angle of the nozzle was calculated with the spray swath width and the height of nozzle. It is described as the angle subtended at the final orifice.

The spray angle of the nozzle was calculated using the formula

$$W=2h\tan\frac{\theta}{2}$$

Where, W is the width of spray cone, mm, h is the height of the spray, mm, θ is the spray angle in degrees

Discharge rate: The amount of liquid ejects from the nozzle in unit time, represented in litre per minute. The relationship between pressure and discharge and pressure was studied.

RESULTS AND DISCUSSION

The properties of liquid calculated in laboratory by using viscometer and pycnometer: The analysis shows (Table 3)

Table 1. Boundary conditions used in ANSYS work bench

Boundary conditions parameters	Values
Fluid	Lime (30%) + Distilled water (70%)
Pressure	1.5 kg/cm^2(147099.75 Pa) 2.5 kg/cm^2(245166 Pa)
Density	1006.06 kg/m^3
Viscosity	1.19 Centi poise
Material of tank	GI sheet
Nozzle material	Ceramics
Domain	FFF

Table 2. Experimental plan for CFD simulation from tank to the nozzle

Independent parameters		Dependent parameters
Nozzles	1. Flat fan nozzle 2. Hallowcone nozzle	1. Eddy viscosity 2. Pressure contour 3. Density contour 4. Pressure volume rendering 5. Eddy viscosity rendering 6. Density volume rendering 7. Discharge rate 8. Swath width 9. Droplet size 10. Spray Angle
Height	1. 400 mm 2. 500 mm	
Pressure	1.5 Kg/cm^2(147099.75 Pa) 2.5 Kg/cm^2(245166 Pa)	
Liquid	L30W70	
density	1006.60kg/m^3	
viscosity	1.19 Cp (0.0011 Pa sec)	

an increase in viscosity and density with an increase in lime juice concentration.

Run calculation: The graphs display the variation in velocity and k-ε turbulent equation during analysis iterations. A scaled residual factor of continuity is used, with values ranging from 1e+02 to 1e+16, indicating the path acquired during operation. This allows for the calculation of any factor value at any time interval for as shown in Figure 4 (a) Flat fan nozzle at 400 mm height and 1.5 kg/cm^{2}pressure, (b) Flat fan nozzle at 500 mm height and 1.5 kg/cm^2 pressure, (c) Flat fan nozzle at 400 mm height and 2.5 kg/cm^2 pressure, (d) Flat fan nozzle at 500 mm height and 2.5 kg/cm^2 pressure, (e)Hallow cone nozzle 400 mm height and 1.5 kg/cm^2 pressure, (f) Hollow cone nozzle 500 mm height and 1.5 kg/cm^2 pressure, (g) Hollow cone nozzle 400 mm height and 2.5 kg/cm^2 and (h) Hollow cone nozzle 500 mm height and 2.5 kg/cm^2 pressure.

Post Processing of ANSYS FLUENT Pictorial Charts

Pressure contours of fluid flow from tank (inlet) to the nozzle (outlet): The chart shows an increase in pressure from the tank to the nozzle outlet due to the flow of fluid. The maximum and minimum pressure values are represented in the color chart. The pressure applied at the boundary condition was 1.5 kg/cm^2 and 2.5 kg/cm^2. The pressure range for flat fan nozzle was 6.26 e+006 Pa (0.63 kg/cm^2) to 2.463e+005 Pa (2.5 kg/cm^2) from (Fig5 (a), (b), (c), (d)). For hollow cone nozzle, the values ranged from 0 Pa to 2.504 e+005 Pa (2.5 kg/cm^2) from (Fig. 5 (e), (f), (g), (h)).

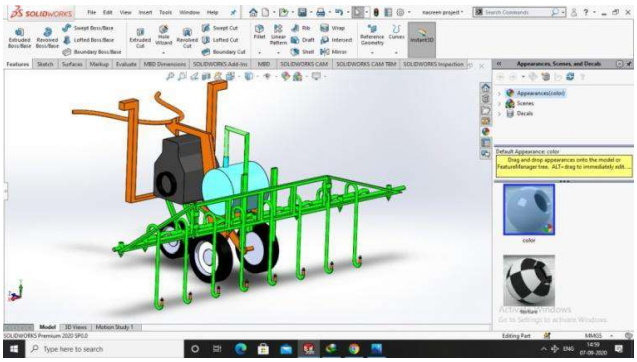

Fig. 3. 3-Dimensional assembled model of self- propelled intra canopy boom sprayer

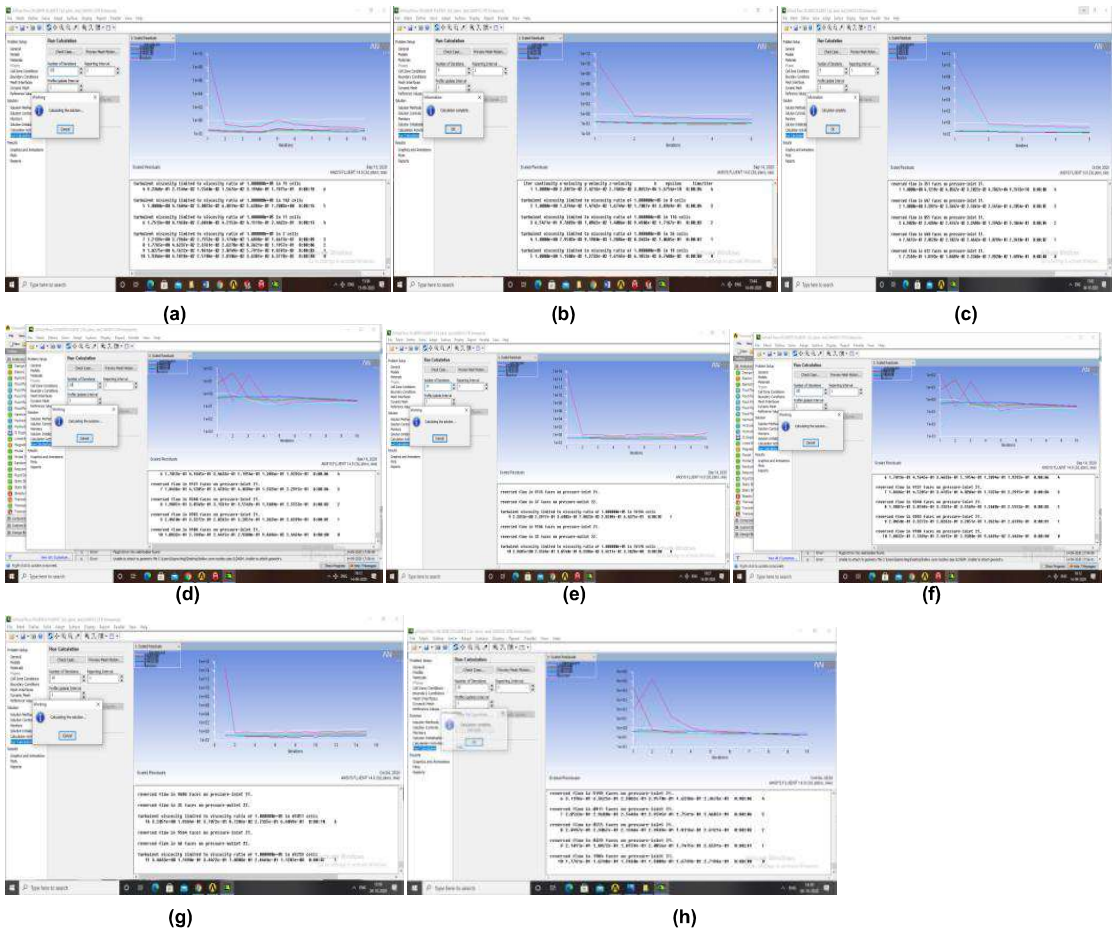

Fig. 4. Initialization of the analysis of ANSYS FLUENT

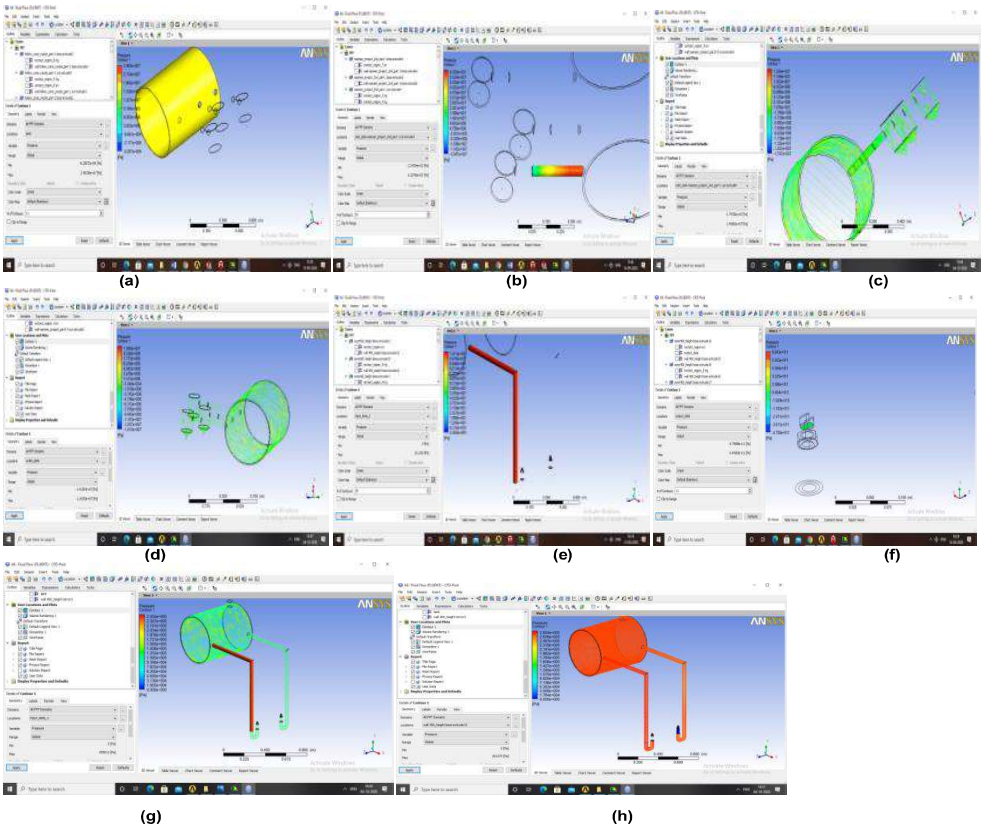

Fig. 5. Pressure contour of the analysis of ANSYS FLUENT from tank to the nozzles

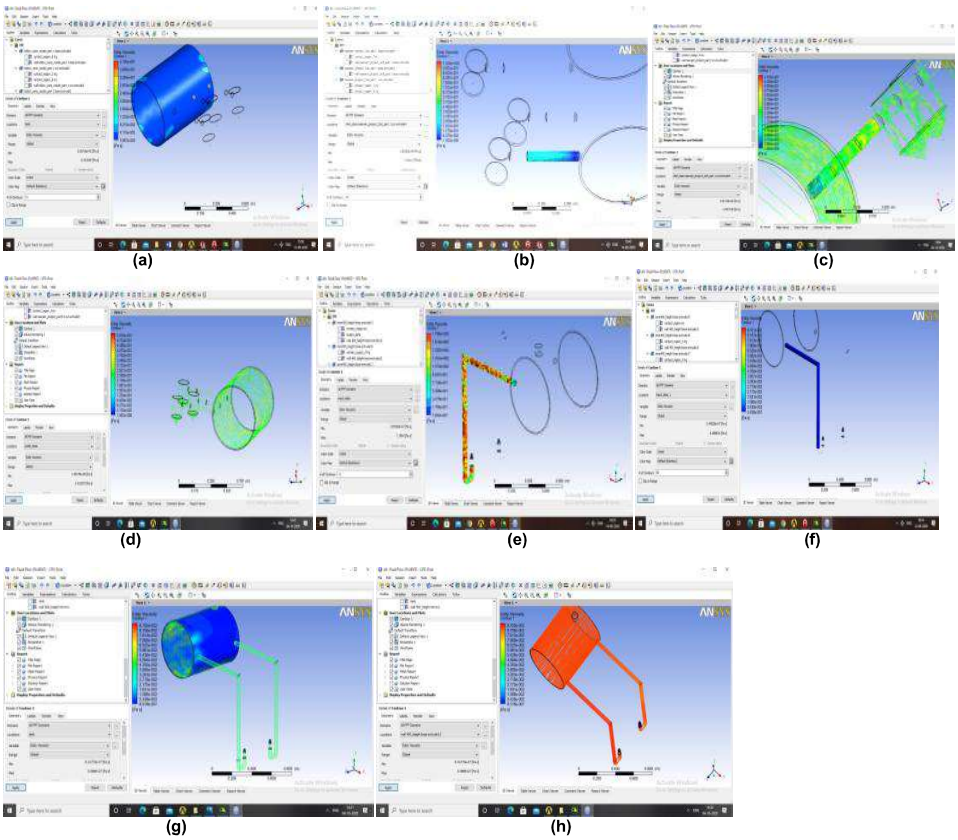

Fig. 6. Eddy viscosity contour of the analysis of ANSYS FLUENT from tank to the nozzles

Eddy viscosity contours of fluid flow from tank (inlet) to the nozzle (outlet): The k-ε turbulent model indicates that the generation of eddies in the tank leads to high viscosity of fluid flow through the nozzles, a coefficient relating to average shear stress and fluid density within a turbulent flow as shown in Figure 6.

Density contours of fluid flow from tank (inlet) to the nozzle (outlet): The density of the fluid flow from tank (inlet) to the nozzles (outlet) was same in all the cases (1.225 kg/m^3) (Fig. 7).

Pressure volume rendering contours of fluid flow from tank (inlet) to the nozzle (outlet): Volume rendering is a technique used to visualize densely spaced three-dimensional data as clouds of various opacity and colors, allowing us to trace the discharge rate, spray width, and droplet size of the flow from the outlet (Fig. 8).

Eddy viscosity volume rendering contours of fluid flow from tank (inlet) to the nozzle (outlet): The eddy viscosity volume showed that viscosity of liquid flow from tank (inlet) to the nozzle (outlet) increases due to the turbulence created by the k–ε turbulent equation (Fig. 9).

Table 3. Properties of liquid calculated in laboratory by using Viscometer and Pycnometer

Lime juice + distilled water (%)	Viscosity (cP)	Density (kg/m^3)
L100W0	1.9	1019.32
L10W90	1.03	995.33
L20W80	1.16	998.72
L30W70	1.19	1006.60
L40W40	1.24	1010.56
L50W50	1.5	1017.35

Table 4. Effect of swath width of flat fan and hollow cone nozzles at different pressures and height

Nozzle type	Operating pressure (kg/cm^2)	Swath width at different heights (mm)	
		400	500
Flat fan nozzle	1.5	254	275
	2.5	356	385
Hallow cone nozzle	1.5	372	384
	2.5	548	558

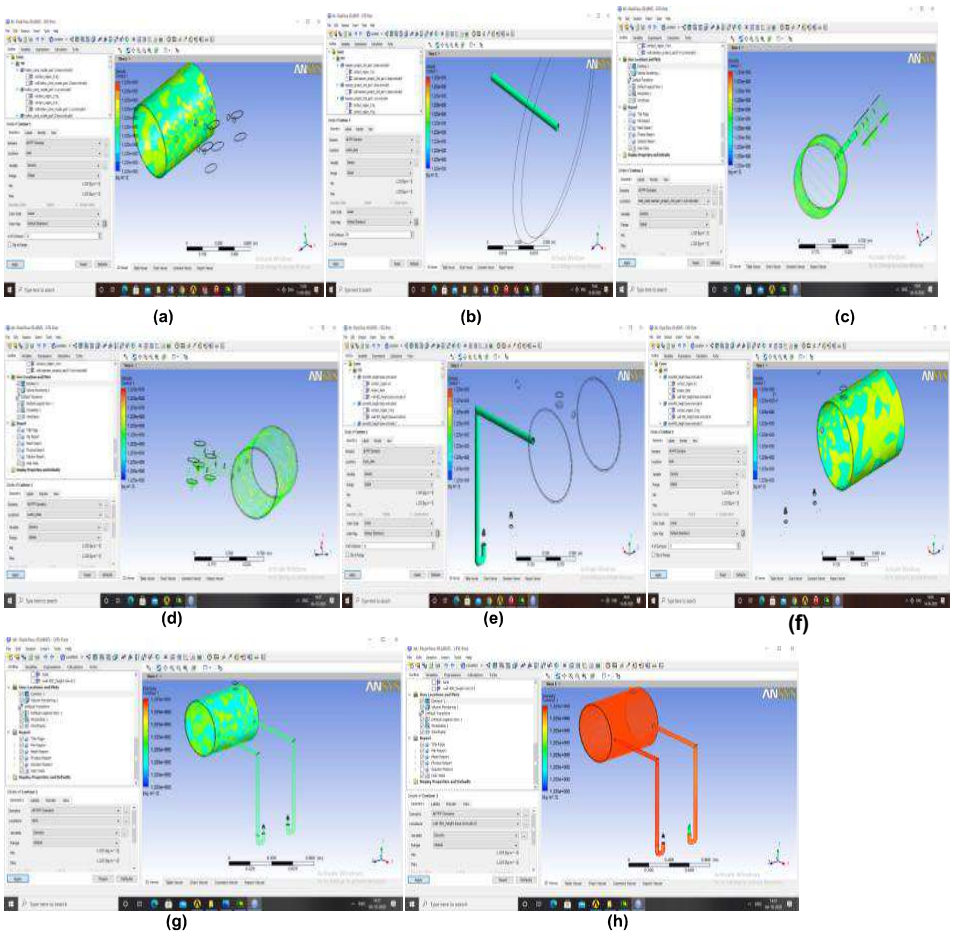

Fig. 7. Density contour of the analysis of ANSYS FLUENT from tank to the nozzles

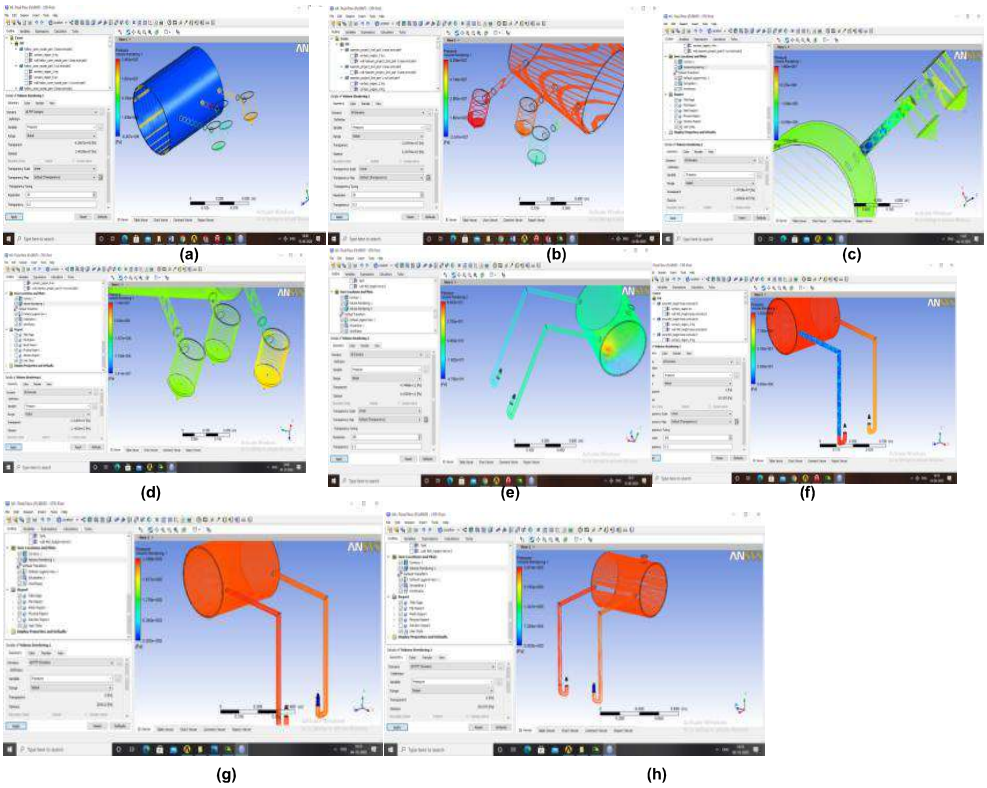

Fig. 8. Pressure volume rendering contour of the analysis of ANSYS FLUENT from tank to the nozzles

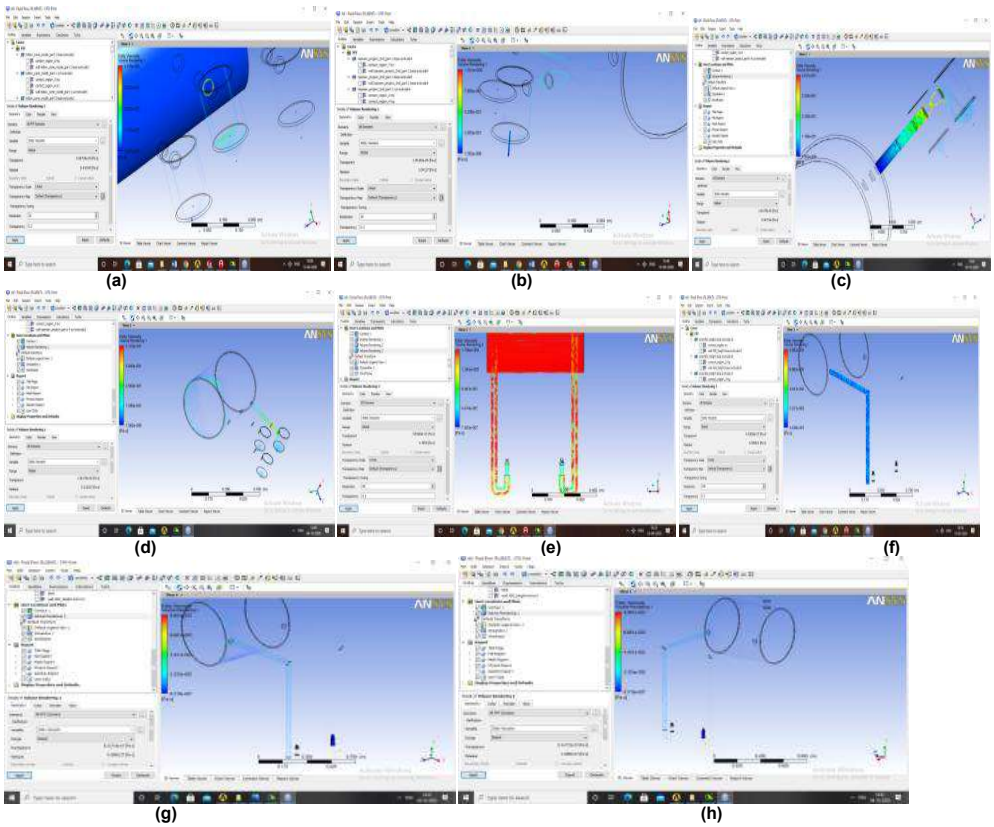

Fig. 9. Eddy viscosity volume rendering contour of the analysis of ANSYS FLUENT from tank to the nozzle

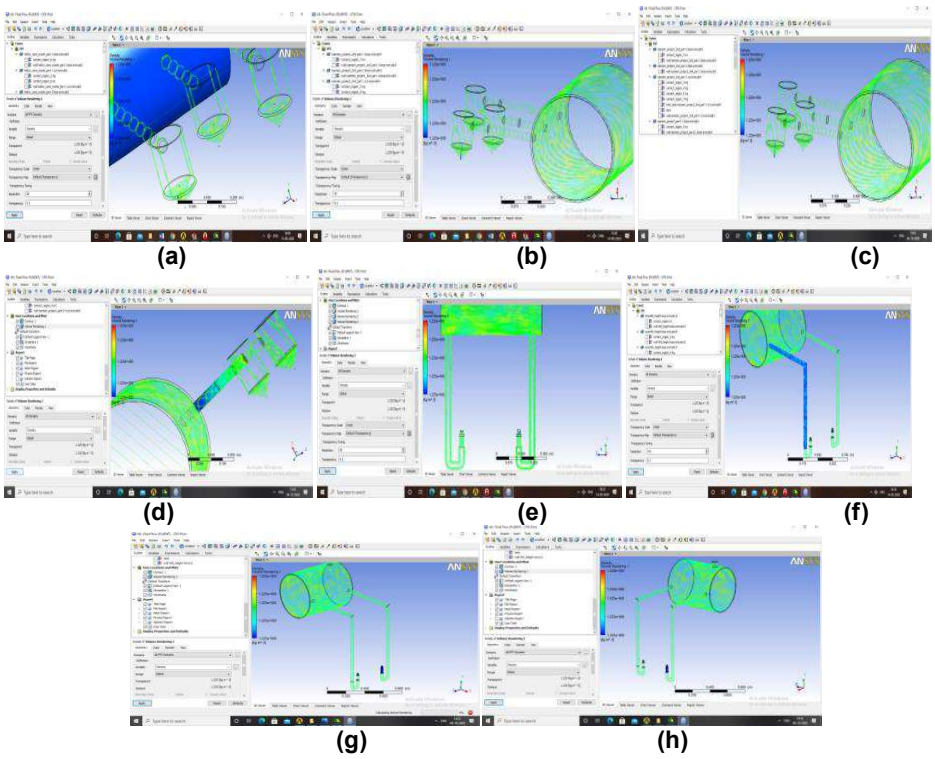

Fig. 10. Density volume rendering contour of the analysis of ANSYS FLUENT from tank to the nozzles

Density volume rendering contours of fluid flow from tank (inlet) to the nozzle (outlet): The density of the fluid flow from tank (inlet) to the nozzles (outlet) is same in all the cases (Fig. 10).

The parameter of nozzle obtained in ANSYS CFD FLUENT analysis is given in Table 4 to 7

Table 5. Effect of operating pressure on discharge rate of nozzles

Nozzle type	Operating pressure (kg/cm^2)	Discharge rate (lit/min)
Flat fan nozzle	1.5	0.223
	2.5	0.254
Hollow cone nozzle	1.5	0.222
	2.5	0.359

Table 6. Effect of operating pressure and height on spray angle of nozzles

Nozzle type	Operating pressure (Kg/cm^2)	Spray angle (degrees) at different heights	
		400 (mm)	500 (mm)
Flat fan nozzle	1.5	35	38
	2.5	48	51
Hollow cone nozzle	1.5	50	51.2
	2.5	68	69

Table 7. Effect of operating pressure on droplet size

Nozzle type	Operating pressure (Kg/cm^2)	Droplet size (microns)
Flat fan nozzle	1.5	284
	2.5	263
Hallow cone nozzle	1.5	336
	2.5	278

CONCLUSION

The study used 3D visualizations to analyze the influence of sprayer design on performance. Computational Fluid Dynamics (CFD) simulations proved valuable for optimizing settings, revealing that pressure, viscosity, and nozzle arrangements significantly affected spray conditions. The model offers potential for extended analysis, including factors like wind speeds and directions, to enhance understanding of sprayer design impact.

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Spatial Distribution of *Thrips tabaci* Lindeman on *rabi* Onion in North Western Himalayan

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***Abstract*:** Spatial distribution of *Thrips tabaci* Lindeman on *rabi* onion was assessed in mid-hill regions of Himachal Pradesh, representing north-western Indian Himalayas. Thrips followed negative binomial distribution in onion. Based on the Lewis index, Index of dispersion, Morisita coefficient of dispersion, Lloyd's mean crowding and Index of patchiness, in early crop growth stages of *rabi* onion, thrips were distributed randomly whereas in later crop stages, thrips distribution was aggregated/ over dispersed/ clumped. Aggregated distribution of thrips was also confirmed by Taylor's power law and Iwao's patchiness regression index with the corresponding values of 1.29 and 2.65. For estimation of thrips population in vegetative, bulb initiation and bulb development stage, the mean number of samples needed were 15476, 760 and 270, respectively at P=0.1 (precision level of 90%),whereas at 80% (P=0.2), relatively small number of samples were needed (869, 190 and 68) for corresponding crop stages.

***Keywords*:** Spatial distribution, *Rabi* onion, Population indices, Population estimation

Onion (*Allium cepa* L.) is one of the major crops grown in different parts of the world mainly in 170 countries for culinary purpose and have medicinal value (Singh et al 2017, FAO 2018). India ranks first in onion production followed by China and accounts for about 25.57 per cent of the world's onion production (FAO 2020). Onion is considered as the most preferred host crop of *Thrips tabaci* Lindeman globally (Gill et al 2015, Pal et al, 2019, Ain et al 2021, Shiberu 2022) and is one of the limiting factors posing serious threat to onion production in all the onion growing regions of the country (Sekine et al 2021). Being polyphagous in nature, feed on around 391 plant species belonging to 64 different families including Asteraceae, Brassicaceae, Fabaceae, Solanaceae and Poaceae (Loredo and Fail 2022). The losses inflicted by *T. tabaci* ranges between 18 to 90 per cent in onion (Pandey et al 2011, Shiberu et al 2013, Tadele and Mulugeta 2014, Soumia et al 2017) in different onion growing regions. Population level of 5 to 30 thrips per plant have been established as the Economic Threshold Level (ETL) in different parts of the world (Tadele and Amin 2014, Tiwari et al 2017). In an ecosystem, individual insect population can change seasonally in response to the availability of resources, behavioral patterns and environment. Comprehensive understanding of insect distribution and the factors that impact utilization of available resources are crucial to establish appropriate sampling plans. Knowledge of dispersion patterns of the pest (random, aggregate or uniform) has wider application in ecological studies, sampling theories as well as in formulation of pest management strategies. Pandey et al (2008) from Jammu and Kashmir (India) observed the clumped distribution of thrips. Since, the distribution parameters of an insect species vary with respect to different factors, the number of sampling units required to estimate the mean density will also vary. Considering this, the present study was aimed to determine the spatial distribution of onion thrips and the samples required for its population estimation which in turn form the basis for decision making in forecasting and thrips management strategies in mid-hill regions of Himachal Pradesh representing north-western Indian Himalayan regions.

MATERIAL AND METHODS

Present investigations were conducted during 2016-17 and 2017-18 at CSK Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India (altitude 1290 m amsl; 32°1'N latitude and 76°5' E longitude). All the recommended agronomic practices were followed in raising the crop excluding plant protection measures. One month old seedlings of Palam Lohit variety were transplanted during second fortnight of December for raising the crop in plot size of 3×3 m with row to row and plant to plant spacing of 15×6 cm, respectively. In-situ observations on population buildup of thrips were recorded following random sampling method

by placing a quadrate of 1 m in onion plot and 10 plants were randomly selected from each quadrate. In total, 300 plants were observed. Observations were recorded at weekly interval starting from first appearance of thrips infestation till final harvesting of the crop.

Analysis of spatial distribution: Spatial distribution of *T. tabaci* was determined by working out various indices of dispersion during two cropping seasons as detailed below:

Variance to mean ratio (VMR): Variance to mean ratio was utilized to determine the thrips distribution as suggested by Patil and Stiteler (1974).

VMR = $S^2/\bar{x}$, where, S^2 = variance, $\bar{x}$ = Mean

The value of VMR = 1, <1 and > 1 for 'Poisson' distribution, positive binomial and negative binomial distribution, respectively. Additionally, VMR provides detail on population dispersion, with the value ranging from <1 (regular) to =1 (random) to >1 (contagious distribution).

Index of clumping of David and Moore (I_{DM}): The distribution of *T. tabaci* was confirmed by estimating the index of clumping (I_{DM}) suggested by David and Moore (1954):

$$I_{DM} = \frac{S^2}{\bar{X}} - 1$$

I_{DM} results in value of zero for Poisson, positive for negative binomial and negative for positive binomial distribution.

Lewis index: Lewis index was worked to determine the dispersion of *T. tabaci* as:

$$\sqrt{\frac{S^2}{\bar{X}}}$$

The value of this index being <1: regular, >1: contagious and =1: random distribution.

Morisita's coefficient of dispersion (I_δ): The following equation was proposed by Morisita (1962) in order to evaluate the uneven distribution coefficient of I_δ.

$$I_\delta = \frac{n \quad Xi\,(Xi-1)}{N\,(N-1)}$$

where, n is the number of sample units, N is the total number of individuals in sample n and Xi is the number of individual in each sample. Large sample test of significance was utilized to determine whether the sampled population varied significantly from random.

$$Z = \frac{(I_\delta - 1)}{\sqrt{\frac{2}{\bar{X}^2}}}$$

Spatial distribution is random if the value of Z is $1.96 \geq Z \geq -1.96$, >1.96 for aggregated and < -1.96 indicated regular distribution (Pedigo and Buntin 1994).

Index of dispersion (I_D): Index of Dispersion was calculated to further confirm the distribution pattern of onion thrips as suggested by Patil and Stiteler (1974).

$$I_D = (n\text{-}1)\ \frac{S^2}{\bar{X}}$$

where, I_D: index of dispersion, n: the number of samples drawn

To test its significance, the I_D coefficient was also worked out as given below:

$$Z = \sqrt{2I_D} - \sqrt{(2v-1}$$

Lloyd's mean crowding ($\bar{X}^*$): It is used to highlight the possible effect of mutual interference or competition among individuals as suggested by Lloyd (1967). The sample estimate of mean crowding ($\bar{X}$) for *T. tabaci* was calculated as

$$\bar{X}^* = \bar{X} + \frac{S^2}{\bar{X}} - 1$$

Index of patchiness ($\bar{X}^*/\bar{X}$): The ratio of mean crowding to mean density ($\bar{X}^*/X$) is known as patchiness index. In a dispersed, random, and clumped distribution, respectively, the values of the function ($\bar{X}^*/X$) are 1, =1, and >1 (Lloyd 1967). The value of ($\bar{X}^*/X$) >2 suggests that clumping being due to environmental factors as well as insect behavior; the value being <2 reveals only environmental factors to influence clumping (Iwao 1968).

Taylor's power law: According to Taylor's power law, population variance (S^2) is proportional to the fractional power of arithmetic mean ($\bar{X}$)*. The log function of $S^2 = a(X)^b$ was used in following form:

$\log S^2 = \log a + b \log (\bar{X})$

where, a: sampling factor, b: aggregation parameter

In which 'a' is sample size-related scaling factor; slope b index of aggregation which in turns recalls (b<1), random (b=1) and aggregated (b>1) dispersion of a population (Taylor 1961).

Iwao's patchiness regression index: This index (Iwao 1968) quantifies the relationship between mean crowding index ($\bar{X}$)* and mean ($\bar{X}$) using the following equation:

$(\bar{X})^* = \alpha + \beta (X)$

Here, α denotes the tendency of crowding (positive) or dispersion (negative). The constant β is related to the pattern in which the insect utilizes its habit and is called density contiguosness coefficient and its interpretation is equivalent to Taylor's power law 'b' (Iwao 1968). The distribution with β>1 corresponds to negative binomial series and the distribution with β=1 to models of randomly distributed colonies were used to test the distribution pattern of thrips.

Desired sample size for population estimation: The number of samples to be taken for estimating thrips population was worked out as suggested by Rojas (1964). Analysis was done at weekly interval starting from the appearance of thrips on crop till the final harvest of the crop.

$$N=\frac{\frac{1}{\bar{x}}+\frac{1}{k}}{D^2}$$

where, N: Number of samples to be drawn, ($\bar{X}$): mean population, k: dispersion parameter worked out as $(\bar{X})^2/(S^2-(\bar{X})$ S^2: variance, D: the desired level of accuracy and was taken as 0.1 and 0.2.

RESULTS AND DISCUSSION

Population dynamics: During cropping season 2016-17, thrips appeared first in 7 standard week (SW) (18 February, 2017). The population density remained low up to 12 SW and peak population of 4.93 thrips/plant was observed on April 22, 2017 (16SW) (Fig. 1). Thereafter, population abruptly declined to 0.09 thrips per plant at final harvest of the crop (May 20, 2017). Whereas, during 2017-18 thrips infestation initiated in second fortnight of February (7-8 SW) and persisted till final harvesting of the crop during mid-May (20 SW). The population levels remained low up to 12 SW and resulted in peak population of 4.65 thrips/plant in third week of April (17 SW).

Spatial distribution: Variance to mean ratio (VMR) to vary between 0.99 to 6.60 (Table 1). The value of VMR was unity on 7 SW and less than unity up to 9SW depicting the population to follow Poisson and positive binomial distribution, respectively. For subsequent observations (10SW onwards) the population followed negative binomial distribution. This was further confirmed by the index of clumping of David and Moore (I_{DM}) which revealed the values being greater than zero and positive in most of the cases, on and after 13 SW depicting the distribution of thrips following negative binomial distribution in later stages of crop growth. The value of index of dispersion (I_D) revealed *T. tabaci* tofollow random distribution with the values ranging between $1.96 \geq Z \geq -1.96$ from 7 to 9 SW. Thereafter, the population trend became aggregated (Z>1.96) for all the values. Morisita coefficient of dispersion (I_δ) also revealed the thrips population to be distributed randomly in early growth stages and aggregated in later stages (10 SW onwards). The hypothesis of aggregation was also confirmed by Lewis index which resulted in the value >1, being aggregated. The values of Lloyd's mean crowding (X*) more than zero (13SW onwards) further confirmed the clumped distribution of thrips. The values of index of patchiness (X*/X*) for most of the observations were greater than unity which revealed that the clumping of thrips on onion being influenced by both the environmental factors as well as insect behaviour.

In early stages of crop growth of *rabi* onion, thrips followed random distribution. But in later crop growth stages, thrips distribution was aggregated/ over dispersed/ clumped. Aggregated distribution of thrips in all the cropping seasons was further confirmed by Taylor's power law and Iwao's patchiness regression in which the value of aggregation parameter (b) and β being positive and > 1, respectively (Fig. 2). The estimates of mean to variance ratio and other dispersion parameters shows that the *T. tabaci* population in onion fields followed the negative binomial distribution. In early

Table 1. Dispersion indices of *Thrips tabaci* in *rabi* onion (Pooled for 2017 and 2018)

SW	Mean population/ plant	Variance	Variance to mean ratio	David & Moore's Index of clumping	Lewis Index	Index of dispersion		Morisita coefficient of dispersion		Lloyd's mean crowding	Index of patchiness
	($\bar{X}$)	(S^2)	(VMR)	(I_{DM})		(I_D)	Z	(I_δ)	Z	($\bar{X}$*)	($\bar{X}$*/$\bar{X}$)
7	0.00	0.00	1.00	0.00	1.00	598.00	-0.01	0.00	-0.06	0.00	0.50
8	0.01	0.01	0.99	-0.01	1.00	596.00	-0.07	0.00	-0.12	0.00	0.25
9	0.01	0.01	0.99	-0.01	1.00	594.00	-0.13	0.00	-0.17	0.00	0.17
10	0.03	0.04	1.78	0.78	1.33	1065.00	11.55	34.29	14.41	0.80	32.12
11	0.09	0.15	1.66	0.66	1.29	994.00	9.99	8.18	11.61	0.75	8.07
12	0.15	0.20	1.39	0.39	1.18	830.10	6.15	3.69	6.76	0.53	3.66
13	0.82	3.14	3.84	2.84	1.96	2301.26	33.24	4.47	49.24	3.66	4.47
14	1.02	2.55	2.51	1.51	1.59	1506.27	20.29	2.49	26.23	2.53	2.49
15	1.43	7.12	4.98	3.98	2.23	2984.54	42.66	3.79	68.95	5.41	3.79
16	3.62	22.21	6.13	5.13	2.48	3670.89	51.09	2.41	88.72	8.75	2.42
17	2.81	18.55	6.60	5.60	2.57	3955.28	54.34	2.99	96.94	8.41	2.99
18	2.23	12.95	5.82	4.82	2.41	3486.12	48.90	3.16	83.41	7.04	3.17
19	1.09	3.83	3.51	2.51	1.87	2103.80	30.27	3.30	43.41	3.60	3.30
20	0.70	1.79	2.55	1.55	1.60	1527.22	20.67	3.21	26.86	2.25	3.21

SW: Standard week

Table 2. Number of samples required for estimating *Thrips tabaci* population in *rabi* onion (Pooled for 2017 and 2018 cropping season)

Crop stage	SW	Number of samples at desired level of precision		Mean number of samples for crop stage at desired level of precision	
		P=0.1	P=0.2	P=0.1	P=0.2
Vegetative	7	29950	7487	15476	3869
	8	14925	3731		
	9	9917	2479		
	10	7112	1778		
Bulb initiation	11	1778	444	760	190
	12	954	239		
	13	469	117		
	14	248	62		
Bulb development to maturity	15	349	87	270	68
	16	169	42		
	17	235	59		
	18	262	65		
	19	322	81		
	20	363	91		

growth stages, the distribution was random which became aggregated during later growth stages. The random distribution at early growth stages of crop can be due to the initial invasion of low number of thrips populations on the crop which later changed to aggregated. At later stages, clumped or aggregated dispersion of *T. tabaci* is common as they are weak and passive fliers which largely depend upon the wind for their dispersion from one plant to another. Thrips colonize for several generations in the same host and their ability to shift and disperse to other host mainly depends on the reproductive success of adults. Other factors such as availability of food resource, adult behavior, protection against natural enemies might contribute their aggregate behavior. Quartey (1982) in Michigan also observed that onion thrips randomly distributed in the beginning of season and clumped subsequently. Pandey et al (2008) also observed the thrips population becoming over dispersed as density increased above one thrips per plant.

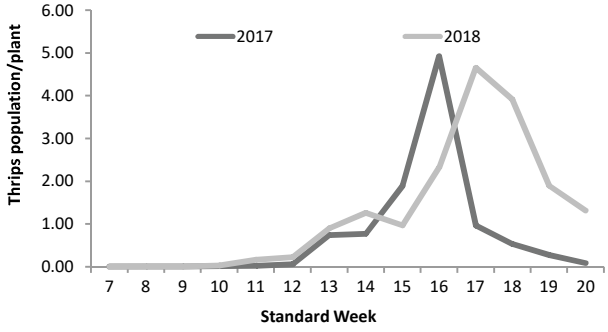

Fig. 1. Mean population of *Thrips tabaci* on onion during 2017 and 2018

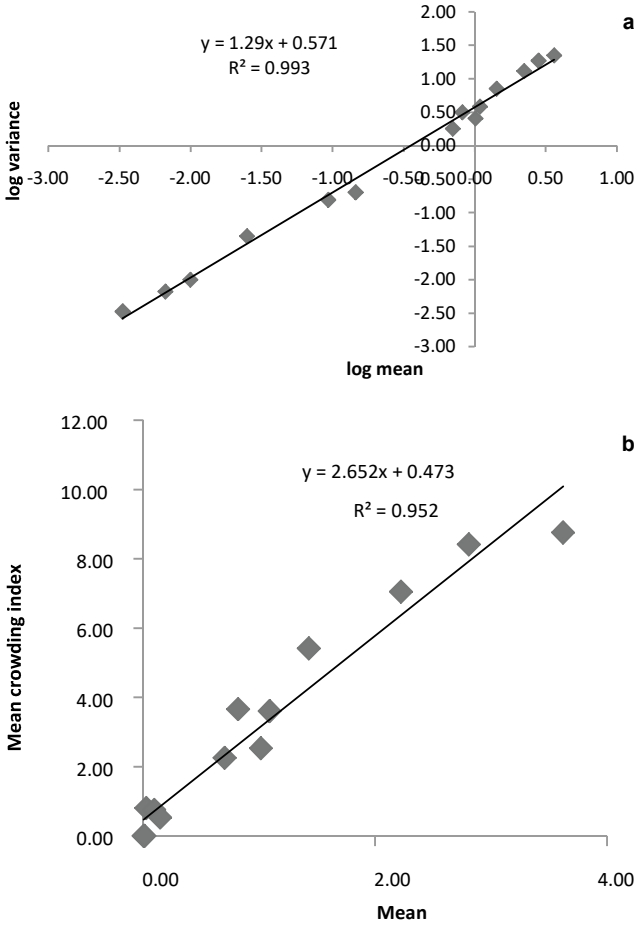

Fig. 2. Parameters for the distribution of *Thrips tabaci* on onion: (a) Taylor's power law; (b) Iwao's patchiness regression index

Desired sample size for population estimation: The desired number of samples required for estimating *T. tabaci* population in *rabi* onion ranged from 169 to 29950 and 42 to 7487 at 10 and 20 per cent precision level, respectively (Table 2). The number of samples required during vegetative stage was more and reduced drastically after 11 SW, coinciding with bulb initiation stage. On the basis of mean number of samples needed for estimating population, the sample size of 15476, 760 and 270 (P=0.1) and 3869, 190 and 68 (P=0.2) was appropriate for vegetative, bulb initiation and bulb development stage of *rabi* onion, respectively. The minimum sample size for thrips estimation utilized at different precision level showed that more samples were needed in early crop stages as distribution of thrips being random in the early crop stages.With the increase in population, distribution became clumped in later crop growth stages resulting the number of samples to be drawn for population estimation to reduce considerably. Deligeorgidis et al (2002) also reported the increase in thrips population caused exponential decrease in sample size.

CONCLUSION

In mid-hill regions of Himachal Pradesh representing north-western Himalayan region, onion thrips infestation initiated during first week of February and persisted till harvesting of the crop to mid of May with peak population occurring during third week of April. The values of all the dispersion indices revealed that thrips follow random distribution during early crop growth stages, whereas, clumped/aggregated/over dispersed in the later stages. The number of samples required for their population estimation were comparatively more in early crop stages as compared to later stages.

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Species Composition of Termites in Coastal Karnataka

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Abstract: Coastal regions have a different climate than inlands; hence may contribute to variation in the diversity of organisms they possess. Termite fauna of coastal Karnataka is understudied. Hence the present investigation was carried out to know the species composition of termites of coastal Karnataka, which includes three districts viz., Udupi, Dakshina Kannada and Uttara Kannada. Soldier caste was used for morphological identification. A total of 29 species belonging to 11 genera and six subfamilies under two families viz., Termitidae and Rhinotermitidae, were recorded. Termitidae was the most dominant family, with 25 species belonging to nine genera. Among subfamilies, Termitinae and Macrotermitinae contributed the highest number of species (nine), followed by Nasutitermitinae (four) and Apicotermitinae (three). Genus *Odontotermes* of subfamily Macrotermitinae was frequently collected and composed of highest number of species (eight).

Keywords: Coastal Karnataka, Termite, Termitidae, *Odontotermes*, Macrotermitinae, Apicotermitinae, Composition, New record

Social insects are one of the most important ecological components of ecosystems. They are among the world's most successful species invading new habitats (Scaduto et al 2012). Among these, termites form a major proportion of the soil macrofauna and highly successful group of insects. They are a marvelous group of social insects with highly evolved organization, caste system and division of labor. They are an ecologically important order with high abundance and biomass in tropical ecosystems (Donovan et al 2000). They play a major role as both destructive pests on economic plants and as beneficial decomposers in natural ecosystems, depending on the species composition of the local communities. Termites belong to the infraorder Isoptera within the order Blattodea and include more than 3500 species described around the world. Termites can be divided into two groups on the basis of habitat; wood dwelling (Kalotermitidae , Archotermopsidae and Stolotermitidae) and subterranean(Rhinotermitidae , Mastotermitidae, Hodotermitidae , Stylotermitidae and Termitidae) (Krishna et al 2013). In India, about 337 species of termites were reported (Paul et al 2018). In southern India, a total of 132 species from five families were reported, of which Termitidae is the dominant family consisting of 101 species from 27 genera and four subfamilies. The regional termite diversity of Karnataka has recently been enriched by the addition of a two new species viz., *Neotermes viraktamathi* (Ranjith et al 2022a) and *Ceylonitermellus sahyadriensis* (Ranjith et al 2022b). Of the 132 species recorded from south India, 60 species belonging to five genera are endemic to the southern region, and the Termitinae was the subfamily with the greatest degree of endemism (Ranjith and Kalleshwaraswamy, 2021). An area-wide distribution may shed more light on conservation. Termites are ubiquitously found in many parts with high diversity, especially in tropical and subtropical regions. Role of termites in different biological processes is very limited regardless of their importance in agriculture and hence it is very essential to understand their biology and ecology, which relies on accurate species identification to a greater extent (Singla et al 2013). Termites are also becoming invasive and hence, thorough identification and regional survey are required (Kalleshwaraswamy 2023). With these points in view, a study was taken up to understand the diversity of termites of coastal Karnataka.

MATERIAL AND METHODS

The study was carried out in three coastal districts of Karnataka viz., Udupi, Dakshina Kannada and Uttara Kannada, which covers a total area of 18,730 km2 with 320 km coastline popularly known as Karavali. This coastline stretches along the eastern shore of the Arabian Sea. The region lies between 12º27' and 15º32' latitude and 74º00' and 75º12' longitudes (ENVIS 2021). The termites were collected in a plastic vial containing 80 per cent ethyl alcohol and brought to the laboratory. The collected specimens were then cleaned with 80 per cent alcohol to eliminate all dirt and debris associated with them using the forceps and camel hairbrush. Then they transferred to a permanent glass vial of 5 ml capacity containing 80 per cent ethyl alcohol and preserved in the Department of Agricultural Entomology,

Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India. Measurements of different body parts are required for species-level identification. For accurate measurement, the alcohol preserved specimens were kept straight and then measured. A special arena/platform was prepared in order to stretch the specimen properly and taken the measurements using an ocular micrometer.

The morphological characters of soldiers are highly variable from species to species for example, the length, shape and size of the mandible, head, labrum, postmentum, pronotum, fontanelle, antennal segments and number of tarsi. Hence these characters were observed. Samples of soldier caste were picked up randomly from the labelled vial. Measurements like the length of head without mandibles, width of head at the base of mandibles (as in case of *Coptotermes*), maximum width of head, length of left mandible, tooth distance of left mandible from the tip, length and width of the labrum, length and width of pronotum, length of postmentum, maximum and minimum width of postmentum were taken. In case of the subfamily Nasutitermitinae of Termitidae, head length along with rostrum, head length without rostrum, length of rostrum and head bulge length were noted, since they differ from other subfamilies or families with respect to head character. For soldierless Apicotermitinae, workers were used for identification. Head length to tip of the labrum, head length to base of the mandible, head width, post clypeus length, post clypeus width, pronotum length, pronotum width, diameter of mid dorsal spot were measured. The observations and measurements were recorded with the help of a stereo-zoom microscope (ZEISS Stemi508) at magnification between 10 to 50X. Measurements were taken with the help of calibrated ocular micrometer (0-10 divisions) and values were converted into mm using the correction factor of the ocular micrometer for each magnification. Soldier specimens of all the species collected were identified to species level using the keys or descriptions as mentioned by Roonwal and Chhotani (1989), Chhotani (1997) and Kalleshwaraswamy et al (2013). Photographs of the collected specimens were taken using Leica M205C microscope attached with a DFC450 camera.

RESULTS AND DISCUSSION

The survey conducted during the investigation period (2019-2021) yielded 172 samples of termites in which 145 were identified till species level and the rest 27 contained only workers or imagoes, which were unable to be identified down to the species level. The taxonomic study indicated the presence of 29 species belonging to 11 genera under six subfamilies belonging to two families viz., Rhinotermitidae Froggatt and Termitidae Latreille. Most of the samples collected were of Termitidae (88.28%) whereas samples of Rhinotermitidae were scarcely collected with 11.72% (Table 1). One new record from Karnataka indicates the need for intensive survey and collections from unobserved habitats like aerial nests, underneath the boulders, logs, leaf litters etc. In terms of species richness also, Termitidae was the most dominant with the highest number of species (25), whereas Rhinotermitidae recorded only four species. This variability in abundance is due to various factors. Most vital among these are climate suitability, availability of food and interactions with other organisms. Family Termitidae is considered as the most evolved group of termites is mainly due to the lack of symbiotic cellulolytic protists in their gut region (Ohkuma 2003). Some of them are mound builders and adapted to various climatic conditions and food habits, which act as key factors for their success (Vidyashree and Kalleshwaraswamy 2018). Among the seven termite families, Termitidae is the largest family covering almost 85 per cent of the known species. It represents approximately 70 per cent of the species in the order Isoptera and is distributed throughout the world (Kambhampati and Eggleton 2000). Termitidae has the maximum number of species (2021) compared to Rhinotermitidae (349) in the world (Constantino and Acioli 2006), which may potentially be the reason for this area's highest level of species diversity.

Rhinotermitidae was represented by two subfamilies viz., Coptotermitinae Holmgren and Heterotermitinae Forgatt. Four species belonging to two different genera (*Coptotermes* and *Heterotermes*) were recorded within this family. Species from subfamily Heterotermitinae Forgatt were frequently collected (11.03%) than Coptotermitinae Holmgren (0.69%). Out of three species collected from Heterotermitinae, *H. indicola* (Wasmann) (Fig. 3) and *H. malabaricus* Snyder (Fig. 4) were represented highest with 4.83% each, followed by *H. balwanti* Mathur and Chhotani (1.38%) (Fig. 5). In Coptotermitinae single species, *C. kishori* Roonwal and Chhotani (Fig. 6) was collected with 0.69 per cent of total samples. Termitidae was comprised of four subfamilies viz., Nasutitermitinae Hare, Termitinae Latreille, Apicotermitinae Grasse and Noirot and Macrotermitinae Kemner. From this family, a total of 25 species belonging to 9 genera were recorded from various locations of coastal Karnataka. The subfamily Macrotermitinae was frequently encountered with 33.10 per cent of total samples, followed by Termitinae (32.41%), Nasutitermitinae (20%) and Apicotermitinae (2.76%) (Table 1).

Nasutitermitinae was the third frequently encountered subfamily during the survey with 20 per cent. It had four

Table 1. Species composition of termites collected from coastal Karnataka

Species	Percentage
Rhinotermitidae	11.72
Heterotermitinae	11.03
Heterotermes balwanti Mathur and Chhotani	1.38
Heterotermes indicola (Wasmann)	4.83
Heterotermes malabaricus Snyder	4.83
Coptotermitinae	0.69
Coptotermes kishori Roonwal and Chhotani	0.69
Termitidae	88.28
Nasutitermitinae	20.00
Trinervitermes biformis (Wasmann)	5.517
Nasutitermes anamalaiensis Snyder	2.76
Nasutitermes brunneus Snyder	4.138
Nasutitermes kali Roonwal and Chhotani	7.59
Termitinae	32.41
Microcerotermes beesoni Snyder	0.69
Microcerotermes cameroni Snyder	2.07
Microcerotermes fletcheri Holmgren and Holmgren	3.44
Microcerotermes pakistanicus Akhtar	17.93
Dicuspiditermes gravelyi Silvestri	2.76
Dicuspiditermes incola Wasmann	0.69
Pseudocapritermes fletcheri Holmgren and Holmgren	2.07
Pseudocapritermes kunjepu Mathew	0.69
Labiocapritermes distortus (Silvestri)	2.07+-
Apicotermitinae	2.76
Speculitermes cyclops Wasmann	1.38
Speculitermes sinhalensis Roonwal and Sen-Sarma	0.69
Speculitermes dharwarensis Akhtar	0.69
Macrotermitinae	33.10
Microtermes obesi Holmgren	4.14
Odontotermes adampurensis Akhtar	0.69
Odontotermes anamallensis Holmgren and Holmgren	4.14
Odontotermes assmuthi Holmgren	3.44
Odontotermes bellahunisensis Holmgren and Holmgren	9.65
Odontotermes guptai Roonwal and Bose	0.69
Odontotermes obesus (Rambur)	6.20
Odontotermes vaishno Bose	1.38
Odontotermes yadevi Thakur	2.76
Total	100

species belonging to two genera (*Nasutitermes* Dudley and *Trinervitermes* Holmgren). When species composition within the subfamily was compared, it revealed that *Nasutitermes* was frequently encountered genus with 72.41 per cent, followed by *Trinervitermes* with 27.59 per cent (Fig. 1). The comparison of individual species of Nasutitermitinae realized that *N. kali* Roonwal and Chhotani (Fig. 7) was frequently collected species (7.59%) followed by *T. biformis* (Wasmann)

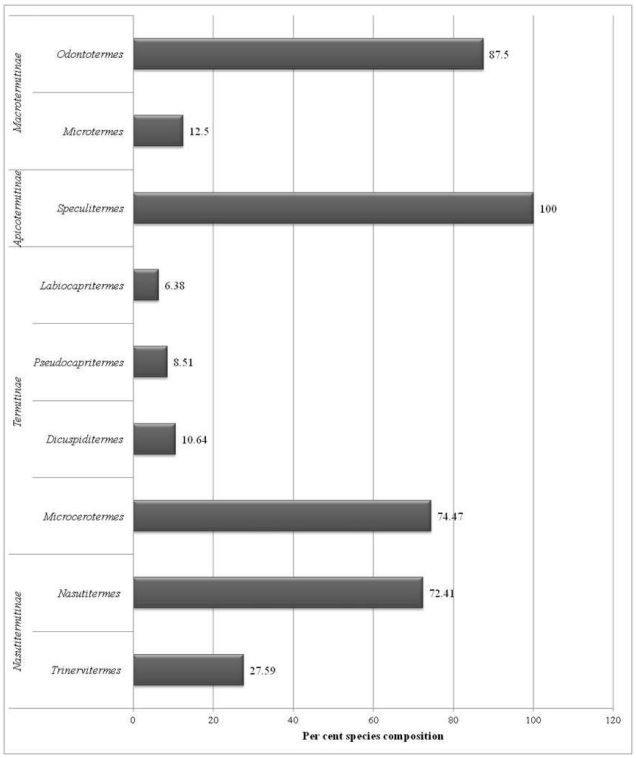

Fig. 1. Per cent composition of species within subfamilies of Termitidae

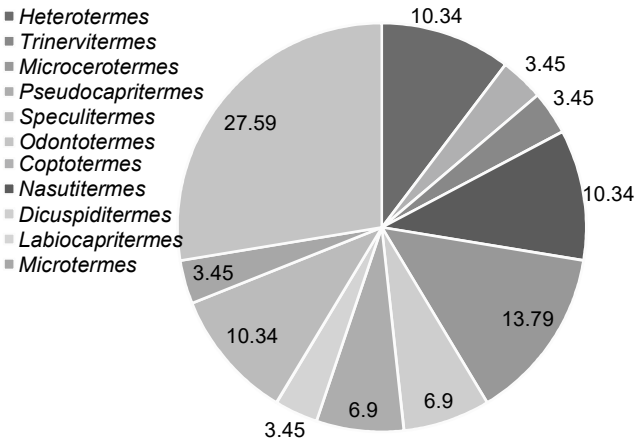

Fig. 2. Per cent species composition of termites collected from coastal Karnataka

(5.52%) (Fig. 8) and *N. brunneus* Snyder (4.14%) (Fig. 9). *N. anamalaiensis* Snyder (2.76%) (Fig. 10) was the sparsely collected species with 2.76 per cent of the total samples collected (Table 1). In Nasutitermitinae, *Nasutitermes* is the most evolved and well-represented genus, having the greatest species diversity. Termitinae was the most diverse subfamily represented by 9 species belonging to four genera. The collection of this subfamily comprised of four species of *Microcerotermes* Silvestri, two species each of *Dicuspiditermes* Krishna and *Pseudocapritermes* Kemner, single species of *Labiocapritermes* Krishna. *Microcerotermes* was the species rich genus under Termitinae. Genus composition within Termitinae indicated that the genus *Microcerotermes* was the frequently collected with 74.41 per cent followed by *Dicuspiditermes* (10.64% of Termitinae) and *Pseudocapritermes* (8.51%). The genus *Labiocapritermes* was least encountered with 6.38 per cent (Fig. 1). Among total species of termites collected within subfamily Termitinae, *Microcerotermes pakistanicus* Akhtar (Fig. 11) was the dominant species collected with 17.93 per cent of the total samples, followed by *M. fletcheri* Holmgren and Holmgren (3.44%)(Fig. 12), *D. gravelyi* Silvestri (Fig. 13) (2.76%), *M. cameroni* Snyder (Fig. 14), *P. fletcheri* Holmgren and Holmgren (Fig. 15) and *L. distortus* (Silvestri) (Fig. 16) each with 2.07 per cent of the total samples. Whereas *M. beesoni* Snyder (Fig. 17), *D. incola* Wasmann (Fig. 18) and *P. kunjepu* Amina and Rajmohana (Fig. 19) were the least encountered with 0.69 per cent of the total samples (Table 1). *P. kunjepu* was the first record from Karnataka. This generic diversity of Termitinae is corroborated with the findings of Ranjith and Kalleshwaraswamy (2021).

Apicotermitinae was represented by single genus *Speculitermes* Wasmann with three species viz., *S. cyclops* Wasmann (Fig. 20), *S. dharwarensis* Roonwal and Chhotani (Fig. 21), *S. sinhalensis* Roonwal and Sen-Sarma (Fig. 22). When individual species collected within Apicotermitinae was compared with total samples revealed that *S. cyclops* was frequently collected sample with 1.38 per cent of the total samples followed by *S. sinhalensis* and *S. dharwarensis*, each with 0.69 percent of the total samples (Table 1). In termites, species identification is majorly based on soldier caste, but most of the genus in this subfamily is soldierless; hence they received less attention. There is a possibility that many common species from this subfamily are not yet described in this region. Therefore intensive survey and identification may yield more species from this subfamily.

Macrotermitinae was the most frequently encountered subfamily during the survey with 33.10 per cent. It was represented by two genera, namely *Odontotermes* Holmgren and *Microtermes* Wasman. The genus *Odontotermes* was the species rich under the subfamily Macrotermitinae with eight species. The genus *Microtermes* was represented by only one species i.e., *M. obesi* (Holmgren) (Fig. 23). Species composition within Macrotermitinae revealed that *Odontotermes* comprised of 87.50 per cent of termite samples collected and *Microtermes* was the least collected (12.50%) (Fig. 1). Comparison of the individual *Odontotermes* species with overall sample revealed that the species *O. bellahunisensis* Holmgren and Holmgren (Fig. 24) was frequently collected species (9.65%) followed by *O. obesus* (Rambur) (Fig. 25) (6.20%), *O. anamallensis* Holmgren and Holmgren (Fig. 26) (4.14%), *O. assmuthi* Holmgren (Fig. 27) (3.44%), *O. yadevi* Thakur (Fig. 28) (2.76%) and *O. vaishno* Bose (Fig. 29) (1.38%). *O. guptai* Roonwal and Bose (Fig. 30) and *O. adampurensis* Akhtar (Fig. 31) were the least encountered species, each represented by 0.69 per cent of the total samples (Table 1).

Analysis on the species diversity of the termites collected

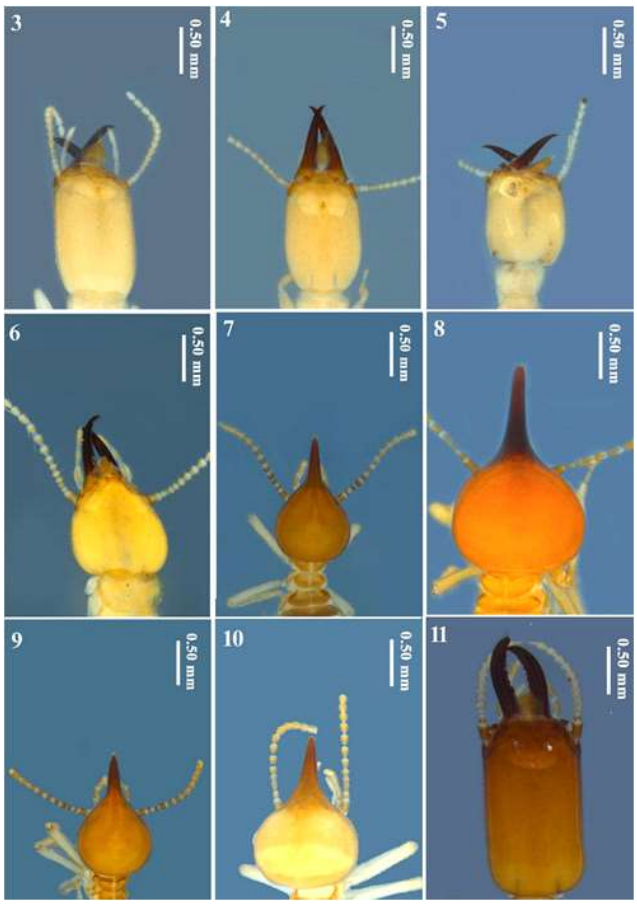

Fig. 3-11. 3. *H. indicola* (Wasmann) 4. *H. malabaricus* Snyder 5. *H. balwanti* Mathur and Chhotani 6. *C. kishori* Roonwal and Chhotani 7. *N. kali* Roonwal and Chhotani 8. *T. biformis* (Wasmann) 9. *N. brunneus* Snyder 10. *N. anamalaiensis* Snyder 11. *Microcerotermes pakistanicus* Akhtar

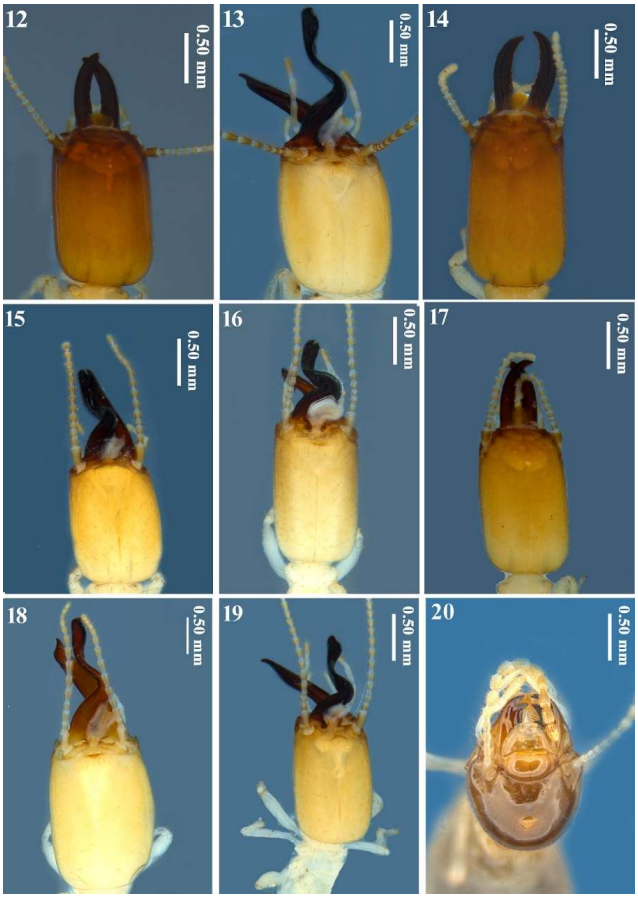

Fig. 12-20. 12. *M. fletcheri* Holmgren and Holmgren 13. *D. gravelyi* Silvestri 14. *M. cameroni* Snyder 15. *P. fletcheri* Holmgren and Holmgren 16. *L. distortus* (Silvestri) 17. *M. beesoni* Snyder 18. *D. incola* Wasmann 19. *P. kunjepu* Amina and Rajmohana 20. *S. cyclops* Wasmann

Fig. 30-31. 30. *O. guptai* Roonwal and Bose 31. *O. adampurensis* Akhtar

during the survey indicated that a total of 27.59 per cent of the termite species falls under the genus *Odontotermes*, followed by *Microcerotermes* (13.79%), *Heterotermes*, *Nasutitermes* and *Speculitermes* each with 10.34 per cent (Fig 2). In the present study, *Odontotermes* was the majorly collected, most

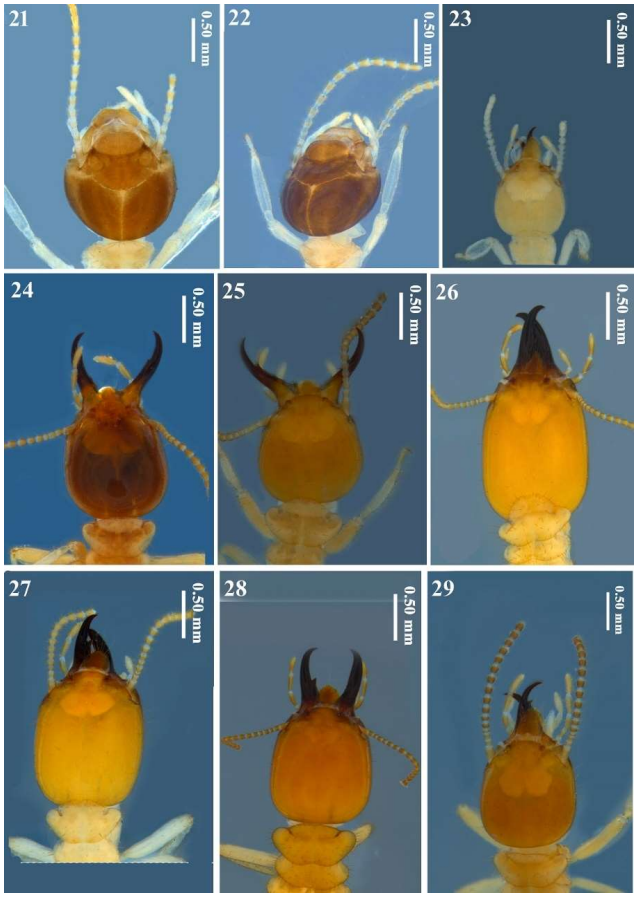

Fig. 21-29. 21. *S. dharwarensis* Roonwal and Chhotani 22. *S. sinhalensis* Roonwal and Sen-Sarma 23. *M. obesi* (Holmgren) 24. *O. bellahunisensis* Holmgren and Holmgren 25. *O. obesus* (Rambur) 26. *O. anamallensis* Holmgren and Holmgren 27. *O. assmuthi* Holmgren 28. *O. yadevi* Thakur 29. *O. vaishno* Bose

diverse and species rich genus of the Macrotermitinae. Similar findings were recorded by Rao et al. (2012) at the Bhadrachalam region of Khammam district of Telangana and Arumugam et al (2020) in Berembun forest reserve, Malaysia. Termites are found in every type of soil. They have both positive and negative effects on the environment. They are the chief decomposers in the ecosystem. By recycling organic materials, modifying soil conditions and improving soil composition and fertility, they serve a critical role. On the contrary to this, they act as destructive insect pests of agricultural, ornamental crops, dry wood, furniture etc. Thus, proper identification and understanding of the species composition in a particular area is essential. Further, molecular identification is suggested for any discrepancies in species delimitation (Vidyashree et al 2018).

CONCLUSION

The study documented termites from costal Karnataka

comprising of 29 species belonging to 11 genera under six subfamilies of two families. Termitidae was the most dominant family, with 25 species belonging to nine genera. The documented species in this study may serve as base for understanding termite species presence and conservation decision making in this region.

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AUTHORS CONTRIBUTION

BS, CMK and MR surveyed for termites. CMK designed the research and interpreted the results. BS and KJM wrote the manuscript and analyzed the data. All authors read and approved the final manuscript.

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New State Records of Water Beetles (Insecta: Coleoptera) from Dhurwa Dam, Ranchi, Jharkhand, India

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Abstract: With over, 13,000 species globally, water beetles exist in almost all types of freshwater habitats, such as rivers, springs, lakes, ditches, puddles, seeps, and groundwater. We examined over 121 water beetle samples from Dhurwa Dam, situated in Indian state of Jharkhand. The identification of the specimens yielded 15 species belonging to 12 genera and 3 families, Noteridae (1 species), Dytiscidae (6 species) and Hydrohilidae (8 species), which are reported for the first time from Dhurwa Dam. Additionally, *Cybister sugillatus* Erichson, 1834, *Leiodytes orissaensis* (Vazirani, 1969) and *Sternolophus rufipes* (Fabricius, 1792) are reported for the first time from Chota Nagpur Plateau in Jharkhand state. These results are based on recent collections, including observation notes on the species habitat. This study is intended to contribute to an appropriate discussion of the diversity of water beetles in the future. With intensive surveys of unexplored areas such as the Chota Nagpur Plateau in the state of Jharkhand, more species of water beetles are expected in the future.

Keywords: Dhurwa Dam, Habitat, Freshwater biodiversity, New record, Water beetles

Water beetles exist in almost all types of freshwater habitats, such as rivers, springs, lakes, ditches, puddles, seeps, and groundwater and vary significantly in size, length and habits. They play several important roles in aquatic ecosystems, contributing to their overall health and balance through their role in nutrient cycling, environmental monitoring, and food webs (Akünal and Aslan 2017). The beetles of the family Dytiscidae are ubiquitous predators in most freshwater habitats, impacting prey populations and other ecological properties of aquatic food webs (Culler et al 2014). Numerous studies have confirmed the role of adult and larval caterpillars in the diet of birds, particularly in water-associated bird species (Culler et al 2014). They also have potential as biological control agents of mosquitoes and demonstrate synergistic effects on mosquito populations (Freitag 2015).

Of the over 13,000 aquatic beetle species discovered worldwide, India represents over 776 species belonging to 137 genera and 17 families in three suborders (Komarek 2003, Jäch and Balke 2008, Chandra et al 2017). Of the four suborders of Coleoptera, the suborder Myxophaga is actually aquatic, while 8 of the 11 extant families of Adephaga are considered aquatic: Gyrinidae, Haliplidae, Meruidae, Noteridae, Amphizoidae, Aspidytidae, Hygrobiidae, and Dytiscidae. As for Polyphaga, the largest suborder of Coleoptera, only 13 of the 150 families are considered truly aquatic: Helophoridae, Epimetopidae, Hydrochidae, Spercheidae, Hydrophilidae, Hydraenidae, Scirtidae, Elmidae, Dryopidae, Lutrochidae, Psephenidae, Cneoglossidae and Eulichadidae.

In recent surveys at Chota Nagpur Plateau in Jharkhand state, we collected water beetle samples from Dhurwa Dam in Jharkhand using various collection methods and assigned them to 15 species. Apart from this, and the few recent studies by Sonali et al (2022), the water beetle fauna of Jharkhand is largely known through works by Nahar (2004) and Vazirani (1968, 1970a, 1970b), which are rather older and do not contain illustrations to identify the species. The purpose of this work is to document and report water beetles from Dhurwa Dam, Jharkhand for the first time, complementing the new geographical distribution in this ecologically significant plateaus. The species are provided with their valid names and their distribution in India and outside India are also reviewed.

MATERIAL AND METHODS

The materials for the present study were collected from Dhurwa Dam (23.288694N, 85.251212E), which is a water reservoir on the ring road of Ranchi district, Jharkhand, built over the Subarnarekha River. The climate is subtropical, and survey was conducted during month of February when climate remain cool and dry and temperatures range from 10°C to 25°C during day. A long-handled D- aquatic net with a 30 cm mouth and 1 mm mesh and small hand sieve was used for collecting the specimens. A total of 121 specimens were collected in 70% ethyl alcohol. After cleaning, the specimens

were stretched, pinned and dried in insect drying chamber for at least 2 days in the laboratory. Male specimens were dissected for examining the male genitalia. After 8–10 hours in 10% KOH at room temperature, male genitalia were transferred to a drop of distilled water, and the cleaned genitalia were subsequently glued on hard cards and pinned along with the specimen. Habitus photographs were taken using a Leica DMC 4500 microscope. The specimens were identified up to the species level by using available literature. For Dytiscidae, the literary works of Vazirani (1968) and Jiang et al (2023) were referred; for Noteridae Toledo (2008) was followed and for Hydrophilidae Schödl (1993), Jia and Wang (2010), and Nasserzadeh and Komarek (2017) were referred. The specimens are deposited in the Zoological Survey of India, Kolkata (NZSI).

RESULTS AND DISCUSSION

A total of 121 examples were examined and identified using morpho-taxonomic approach. Identification of collected water beetle samples from Dhurwa Dam revealed a total of 15 species belonging to 12 genera and 3 families, Noteridae (1 species), Hydrophilidae (8 species) and Dytiscidae (6 species). The species account of the recorded species from the study area is as follows:

Suborder Adephaga Schellenberg 1806

Family Noteridae Thomson 1860

Subfamily Noterinae Thomson 1860

Tribe Noterini Thomson 1860

1. *Canthydrus laetabilis* (Walker, 1858) (Fig. 1a)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 9 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andhra Pradesh, Assam Bihar, Delhi, Gujarat, Himachal Pradesh Jammu and Kashmir, Jharkhand, Kerala Madhya Pradesh, Maharashtra, Meghalaya, Odisha, Punjab, Puducherry, Rajasthan, Sikkim, Telangana, Tripura, Uttarakhand, Uttar Pradesh, and West Bengal (Vazirani 1968, Ghosh et al 2023). Elsewhere: Bangladesh, Myanmar, Nepal and Pakistan (Nilsson 2011).

Remarks: The species is widespread in India. The samples in the present study were collected from slow-moving water on the sides of the dam with vegetation growth. The species has also been reported from Hazaribagh Wildlife Sanctuary, Ranchi and West Singhbhum districts of Jharkhand (Vazirani 1968).

Family Dytiscidae Leach, 1815

Subfamily Cybistrinae Sharp, 1880

Tribe Cybistrini Sharp, 1880

2. *Cybister* (*Cybister*) *tripunctatus lateralis* (Fabricius 1798) (Fig. 1b)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 8 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Islands, Andhra Pradesh, Assam, Delhi, Gujarat, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh, and West Bengal. Elsewhere: Afghanistan, Bangladesh, Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka, China, Cyprus, Iran, Iraq, Japan, Kyrgyzstan, Mongolia, Russia, Syria, Tajikistan, Turkey, Turkmenistan, Uzbekistan, and Europe (Ghosh and Nilsson 2012).

Remarks: This species is widespread in artificial habitats such as irrigation canals, flooded rice fields, open swamps, fish ponds and ornamental ponds (Jiang et al 2023). They are predators and are considered pests in fish farming because they attack fish fry and parts of aquatic food webs. The species was reported by Vazirani (1968) from Dumka, Hazaribagh, Ranchi and West Singhbhum districts of Jharkhand.

3. *Cybister* (*Melanectes*) *sugillatus* Erichson, 1834 (Fig. 1c)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490° E, 08.ii.2022, 6 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman and Nicobar Islands (Great Nicobar Island), Assam, Bihar, Himachal Pradesh, Jharkhand (new record), Madhya Pradesh, Maharashtra, Manipur, Odisha, Sikkim, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh, and West Bengal. Elsewhere: Afghanistan, Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka, China, Indonesia, Japan, and Philippines (Ghosh and Nilsson 2012, Ghosh and Gupta 2022).

Remarks: This species is reported for the first time from Jharkhand. At the collection site, 6 specimens were collected along with 8 specimens of *C. tripunctatus lateralis*.

Subfamily Dytiscinae Leach, 1815

Tribe Hydaticini Sharp, 1880

4. *Hydaticus ricinus* Wewelka 1979 (Fig. 1d)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 7 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Assam, Jharkhand, and Tamil Nadu. Elsewhere: Afghanistan, Bhutan, China, Laos, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, and Vietnam (Ghosh and Nilsson 2012, Sonali et al 2022).

Remarks: This is the first report for Ranchi district, Jharkhand, previously reported by Sonali et al (2022) from Hazaribagh Wildlife Sanctuary. Samples were collected from

the sides of the reservoir where there was vegetation growth and water seeped into surrounding farms.

Subfamily Hydroporinae Aubé, 1836

Tribe Bidessini Sharp, 1880

5. *Hydroglyphus inconstans* (Régimbart 1892) (Fig. 1e)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 16 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Islands, Andhra Pradesh, Assam, Goa, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttarakhand, and West Bengal. Elsewhere: Bangladesh, Bhutan, Myanmar, Nepal, Sri Lanka, China, Indonesia, Japan, Malaysia and Taiwan (Ghosh and Nilsson 2012).

Remarks: This species was reported by Vazirani (1968) from Hazaribagh, Ranchi and West Singhbhum districts of Jharkhand.

6. *Leiodytes orissaensis* (Vazirani 1969) (Fig. 1f)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 8.ii.2022, 4 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Gujarat, Jharkhand (new record), Odisha, and West Bengal. Elsewhere: Bangladesh and Pakistan (Ghosh and Nilsson 2012).

Remarks: This is the first record of this species from Jharkhand. *Leiodytes indicus* (Régimbart, 1892) is the other species in the genus reported from Jharkhand by Vazirani (1968).

Subfamily Laccophilinae Gistel, 1856

Tribe Laccophilini Gistel, 1856

7. *Laccophilus inefficiens* (Walker 1859) (Fig. 2a)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, E 85.2490°E, 08.ii.2022, 5 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Islands, Andhra Pradesh, Assam, Bihar, Goa, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Punjab, Rajasthan, Sikkim, Tripura, Tamil Nadu, Uttarakhand, Uttar Pradesh, and West Bengal. Elsewhere: Bangladesh, Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka, Indonesia, Iran, and Malaysia (Ghosh and Nilsson 2012).

Remarks: This species was previously reported by Vazirani (1968) from Deoghar, Hazaribagh, Ranchi and West Singhbhum districts of Jharkhand.

Suborder Polyphaga Emery, 1886

Family Hydrophilidae Latreille, 1802

Subfamily Hydrophilinae Latreille, 1802

Tribe Berosini Mulsant, 1844

8. *Berosus* (*Enoplurus*) *chinensis* Knisch, 1992 (Fig. 2b)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 8 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Jammu & Kashmir, Jharkhand, Madhya Pradesh, Puducherry, Rajasthan, Sikkim, and Uttar Pradesh (Sonali et al 2022, Ghosh et al 2023). Elsewhere: Afghanistan, Arabian Peninsula, Bangladesh, China, Iran, Myanmar, Nepal, Pakistan, Thailand and Vietnam (Hansen 1999).

Remarks: This species was recently detected in the Hazarabagh Wildlife Sanctuary by Sonali et al (2022).

9. *Berosus* (*Berosus*) *pulchellus* MacLeay, 1825 (Fig. 2c)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 23 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Islands, Andhra Pradesh, Assam, Bihar, Dadra Nagar Haveli, Daman, Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Nagaland, Odisha, Puducherry, Punjab, Rajasthan, Sikkim, Tamil Nadu, Telangana, Uttarakhand, Uttar Pradesh, and West Bengal. Elsewhere: Australia, Bangladesh, China, Indochina, Indonesia, Iran, Japan, Laos, Saudi Arabia, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam (Schödl 1993, Sonali et al 2022, Ghosh et al 2023).

Remarks: This is a widespread species in the Indo Malayan, Palearctic and Australasian geographical regions.

10. *Regimbartia attenuata* (Fabricius 1801) (Fig. 2d)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 2 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Islands, Andhra Pradesh, Bihar, Dadra Nagar Haveli, Diu, Gujrat, Maharashtra, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Madhya Pradesh, Manipur, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttarakhand, Uttar Pradesh, West Bengal, and Telangana (Ghosh and Hedge 2013, Sonali et al 2022). Elsewhere: Afghanistan, Australia, China, Cambodia, Indonesia, Japan, Malaysia, Myanmar, New Guinea, Oman, Pakistan, Philippines, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam, and Yemen (Hansen 1999).

Remarks: This is a widespread species in the Indo Malayan, Palearctic and Australasian geographical regions and in the case of India, it is one of the most common water beetle species.

Tribe Hydrophilini Latreille, 1802

11. *Hydrophilus olivaceous* (Muller, 1764) (Fig. 2e)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 1 ex., leg. Shipra Sonali [NZSI].

Distribution in India: Andhra Pradesh, Bihar, Chhattisgarh, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan, Tamil Nadu, Telangana, and West Bengal. Elsewhere: China, Nepal, Myanmar, Malaysia, Thailand, and Vietnam (Hansen 1999, 2004, Mukhopadhyay and Sengupta 2004).

Remarks: This species is mainly distributed in peninsular India, with few records from Palearctic regions such as China and Nepal.

12. *Sternolophus decens* Zaitzev, 1909 (Fig. 2f)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 11 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Bihar, Jharkhand, Madhya Pradesh, Maharashtra, and Uttarakhand. Elsewhere: Djibouti, Oman, Saudi Arabia, United Arab Emirates, Iran, Pakistan, and Nepal (Hansen 1999, Nasserzadeh and Komarek 2017, Sonali et al 2022).

Remarks: This species, which is only known from a few places in India, is even distributed as far as the Arabian Peninsula.

13. *Sternolophus rufipes* (Fabricius 1792) (Fig. 2g)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 6 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Assam, Dadra Nagar Haveli and Diu, Jammu & Kashmir, Jharkhand (new record), West Bengal, Sikkim, Tamil Nadu, Maharashtra, Meghalaya, Uttar Pradesh, Manipur, Andhra Pradesh, Bihar, Punjab, Tripura, Delhi, Madhya Pradesh, Rajasthan, Uttarakhand, Himachal Pradesh, Odisha, Haryana, and Kerala. Elsewhere: China, Indonesia, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam, Japan, South Korea, and Myanmar (Hansen 1999, Nasserzadeh and Komarek 2017).

Remarks: The present record is the first record of this species from the state of Jharkhand. This is a widespread species in the Indomalayan and Palearctic geographical regions and is one of the most common water beetle species in India.

Subfamily Acidocerinae Zaitzev, 1908

Tribe Acidocerini Zaitzev, 1908

14. *Helochares pallens* (MacLeay 1825) (Fig. 2h)

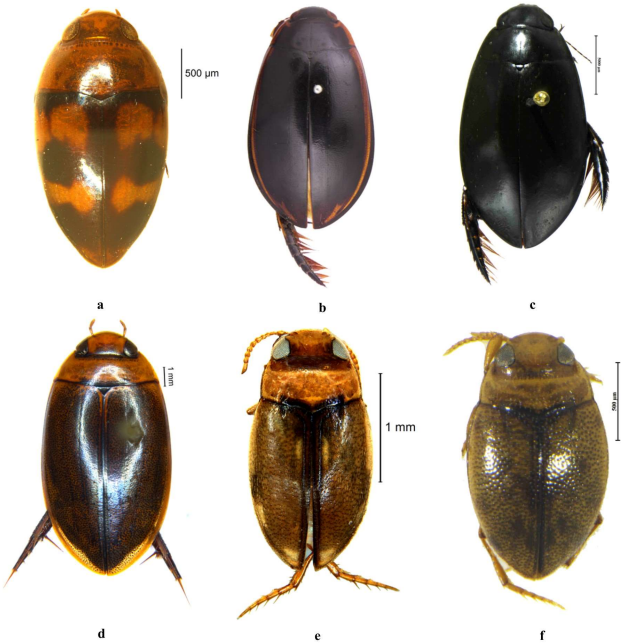

Fig. 1. Habitus of water beetles. (a) *Canthydrus laetabilis*. (b) *Cybister tripunctatus lateralis*. (c) *Cybister sugillatus*. (d) *Hydaticus ricinus*. (e) *Hydroglyphus inconstans*. (f) *Leiodytes orissaensis*

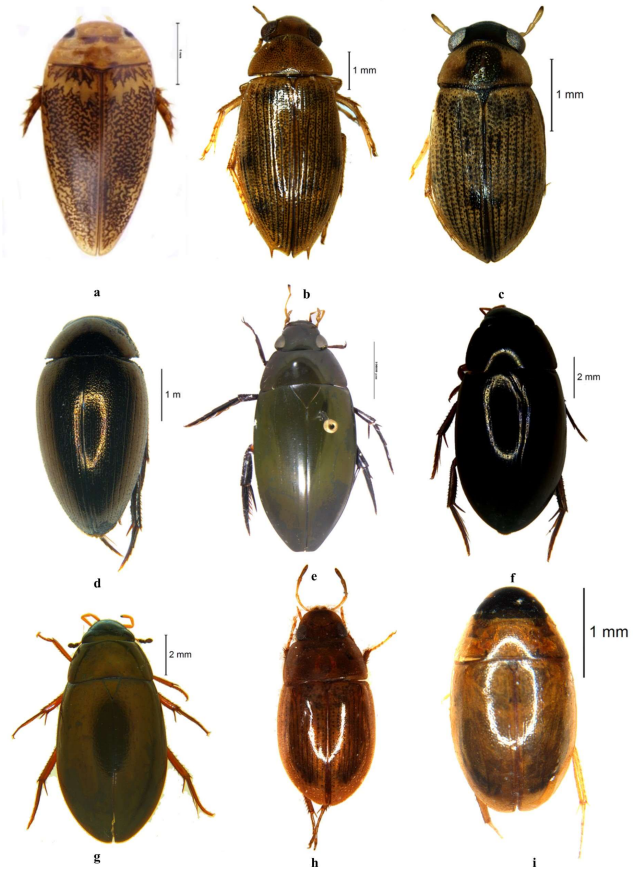

Fig. 2. Habitus of water beetles. (a) *Laccophilus inefficiens*. (b) *Berosus chinensis*. (c) *Berosus pulchellus*. (d) *Regimbartia attenuata*. (e) *Hydrophilus olivaceous*. (f) *Sternolophus decens*. (g) *Sternolophus rufipes*. (h) *Helochares pallens*. (i) *Enochrus esuriens*

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 5 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andhra Pradesh, Assam, Bihar, Dadra Nagar Haveli, Daman and Diu, Jammu and Kashmir, Jharkhand, Uttar Pradesh, Madhya Pradesh, Manipur, Sikkim, Telangana, and West Bengal (Mukhopadhyay and Sengupta 2004, Ghosh et al 2018, Sonali et al 2022). Elsewhere: Afrotropical, Benin, Botswana, Chad, Congo, Ethiopia, Ghana, Guinea, Kenya, Madagascar, Namibia, Rwanda, South Africa, Sudan, Tanzania, Yemen, and Zambia (Hansen 1999).

Remarks: This is a widespread species in the Indo-Malayan, Palearctic and Afrotropical geographical regions and in the case of India, it has also been recorded in the Himalayas and the Indian peninsula.

15. *Enochrus* (*Methydrus*) *esuriens* (Walker 1858) (Fig. 2i)

Material examined: India: Jharkhand, Ranchi, Dhurwa Dam, 23.2898°N, 85.2490°E, 08.ii.2022, 7 exs., leg. Shipra Sonali [NZSI].

Distribution in India: Andaman & Nicobar Island (Nicobar Island), Andhra Pradesh, Dadra Nagar Haveli, Daman, Jammu & Kashmir, Jharkhand, Madhya Pradesh, Manipur, Maharashtra, Odisha, Punjab, Sikkim, Telangana, Uttarakhand, Uttar Pradesh, and West Bengal. Elsewhere: Bangladesh, China, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand, Vietnam, Japan, Saudi Arabia, South Korea, Australia, Fiji, New Caledonia, New Guinea, Solomon Island, and Vanuatu (Hansen 1999, Mukhopadhyay and Sengupta 2004, Sonali et al 2022).

Remarks: This is a widespread species in the Indo-Malayan, Palearctic and Afrotropical geographical regions and in the case of India, it has also been recorded in the Himalayas and the Indian peninsula.

A total of 121 examples were studied from Dhurwa Dam, Jharkhand, India using a morpho-taxonomic approach. Identification of collected water beetle samples revealed a total of 15 species belonging to 12 genera and 3 families, Noteridae (1 species), Hydrophilidae (8 species) and Dytiscidae (6 species). Dytiscidae comprises the genera, *Cybister* Curtis (2 species), *Hydaticus* Leach (1 species), *Laccophilus* Leach (1 species), *Leiodytes* Guignot (1 species), and *Hydroglyphus* Motschulsky (1 species), and Hydrophilidae *Berosus* Leach (2 species), *Enochrus* Thomson (1 species), *Helochares* Mulsant (1 species), *Hydrophilus* Geoffroy (1 species), *Regimbartia* Zaitzev (1 species) and *Sternolophus* Solier (2 species). Noteridae includes only a single species. All of these species have been reported for the first time from the study area. However, *Cybister* (*Melanectes*) *sugillatus* Erichson, 1834, *Leiodytes orissaensis* (Vazirani, 1969), and *Sternolophus rufipes* (Fabricius, 1792) have been recorded for the first time from the state of Jharkhand. Similar studies by Sonali et al. (2022) reported 38 water beetle species from 22 genera, six subfamilies and three families from Hazaribagh Wildlife Sanctuary, Jharkhand. Insect diversity in Indian freshwater includes more than 5014 species/subspecies in 9 major groups (Chandra and Gupta 2022a, b), which are severely affected by over-exploitation, water pollution, flow modifications, habitat destruction or degradation, invasion of exotic species and hydropower (Gatti 2016). The water bodies in Ranchi district are polluted by domestic sewage and runoff from agricultural areas and hospitals (Kirti et al 2012), which is likely to impact insect communities in the region. Therefore, measures must be taken at the administrative level for better biodiversity management in the region.

CONCLUSIONS

The present study on water beetles from Dhurwa Dam, Jharkhand, India has provided valuable insights into the diversity and distribution of these species in the study area. A total of 15 species from 12 genera and 3 families, Noteridae (1 species), Hydrophilidae (8 species) and Dytiscidae (6 species), provide an overview of the water beetle community in the region, with 3 new records from the state of Jharkhand. The study not only presents the current diversity and distribution of water beetles in the Chota Nagpur region of the Indian state of Jharkhand, but also highlights the urgency of conservation efforts to ensure the continued existence of these species. The present work resulted in a database of aquatic beetles that will assist in future work to conserve, conserve and expand the local biodiversity of these beetles.

AUTHORS CONTRIBUTION

S. Sonali: Collection, preservation and identification of specimens, and writing of the manuscript, P. Basu: Identification and writing of the manuscript, S.K. Ghosh: Identification of specimens, D. Gupta: Identification of specimens and writing the manuscript.

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Assessment of Lac Diversity and Indigenous Technical Knowledge in North East Region of India

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***Abstract*:** Lac insects are commercially harnessed for economically important resin, dye and wax. Of the nine genera and 102 species of lac insects reported from all over the world, two genera and 22 species are found in India. Natural populations of *Kerria spp.* are distributed throughout the country and NE region houses valuable lac insect genetic resources in the country. Hence, surveys were carried out for lac associated faunal and floral diversity from seven states in North East India. Lac insects and associated fauna (predators and parasitoids) were observed and collected from Assam, Manipur, Meghalaya, and Nagaland on various lac host plants, *viz., Acacia auriculiformis, Cajanus cajan, Ficus spp, Mallotus philippensis, Malvaviscus penduliflorus* and *Ziziphus mauritiana.* Distinct lac host species were also reported in NE region. Lac insect from Manipur was recorded as morphologically new species, *Kerria manipurensis.* Lac insects collected from Manipur, Assam and Nagaland revealed 89–97% homology with both LIK31 and LIK23 (both *K. chinensis* lines) through molecular analysis. Different ant species *viz., Crematogaster spp* and *Technomyrmex albipes* were also found associated with lac insect. *The occurrence* of lac host plants, *viz., Acacia auriculiformis, Albizia lebbek, A. lucida, A. saman, Butea monosperma, Cajanus cajan, Ficus spp., Kydia calycina* (Boldubak), *Macaranga denticulate* (Chhagru), *Mallotus philippensis, Malvaviscus penduliflorus, Ziziphus mauritiana,* and the perennial Red gram variety were also collected during the survey. Indigenous Technical Knowledge (ITK) information related to lac was also collected from north-east India during the survey. These ITK's were used in lac culture as well as medicinal purposes. It is envisaged that the distinct lac insect and host *species* would be a valuable resource in developing new lac insect + host plant combinations for enhancing lac productivity of the country.

***Keywords*:** Lac insects, Lac hosts, Diversity, ITK and North East India

Lac-insects (Tachardiidae) are commercially harnessed for economically important resin, dye, and wax. India is the world's richest lac biodiversity nation containing 21.8 per cent diversity (Sharma et al 2006). The Indian lac-insect, *Kerria lacca* (Kerr) is the most important and widely exploited insect for lac cultivation. More than 400 lac host plants have been observed to carry lac insects throughout the world. Major host plants of *K. lacca* are *Butea monosperma* Lam. (*palas*), *Schleichera oleosa* (Lour.) Oken. (*kusum*), *Ziziphus mauritiana* Lamk (*ber*), *Ficus spp.*, *Cajanus cajan* (L.) *Mill* sp. (Red gram*),* and *Flemingia spp.* Lac cultivation is prominent in Jharkhand, Chhattisgarh, West Bengal, and Odisha, mainly using *K. lacca*. Natural populations of *Kerria spp*. are distributed throughout the country (Mohanasundaram et al 2018). Lac was widely cultivated in North-East India even before the 19th century, but its production contribution at present is insignificant. North eastern region particularly Assam is one of the biodiversity hotspots with approximately 4000 species of plants but exploitation of these natural flora for commercial production of lac is very limited (Rahman et al 2021). *Kerria chinensis*, which is the Chinese commercial species and also the major species of lac insect cultivated in Thailand (Chen et al 2011), is cultivated to a certain extent in the northeastern states of India. The lac insect ecosystem is a complex multi-trophic web of flora and fauna. It represents a rich biodiversity, which besides lac insects, lac-host plants includes several predators of lac insects, beneficial parasites, harmful parasites, etc. (Sharma et al 2006). The NE region has valuable lac insect genetic resources in the country. Hence, surveys were carried out for collecting biodiversity of lac associated fauna, flora diversity and studying the Indigenous Technical Knowledge (ITK) in lac field. Populations of collections from NE states were cultured at the National Lac Insect Germplasm Centre at ICAR-National Institute of Secondary Agriculture (NISA), Ranchi for morphological, biological attribute studies.

MATERIAL AND METHODS

Survey and collection of lac insects and lac host plants: To know the availability of lac insect species, extensive surveys were carried out in seven states *viz.,* Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and

Tripura, covering 30 districts. Surveys were undertaken during February 2013, October 2013, 2014, & 2016 and November 2009, 2010 & 2018 and February 2020. Before, undertaking the survey, information on the occurrence of lac insects was acquired from organizations *viz*., Agricultural Universities, State Forest Department and Local *Krishi Vigyan Kendra* about lac insect/host plant availability. The lac insect populations were located through visual observations and through binoculars, especially on reported lac host species in the peripheral area. The presence of lac insect was located by the blackish appearance or dried twigs or branches of lac host plants nearby waterlogged areas, either by eye sight or through binoculars. If lac insects were noticed, then the branch/ twigs having the lac insect colonies were cut and covered with moistened cotton plugs at both ends to avoid dehydration and kept in the 60 mesh synthetic net with proper label. Altitude, latitude and longitude of the location were marked using GPS (GARMIN OREGON® 550). If, proper lac insect stage (larviposition) was not observed, visits were made subsequently to the respective places for collection and its conservation at appropriate stage. Collected lac insects were brought to ICAR- National Institute of Secondary Agriculture (ICAR-NISA), Ranchi and inoculated live on potted plants of *Flemingia macrophylla* (Willd.) Merr. in National Lac Insect Germplasm Centre (NATLIGEC) for further study. Lac insect sample collected from Manipur was identified at ICAR-Indian Agricultural Research Institute (IARI), New Delhi, on morphological basis. Evaluation of biological attributes of lac insects collected from North East India *viz*., Assam, Manipur, Meghalaya and Nagaland for *rangeeni baisakhi* (summer season) and *katki* (rainy season) crop during two consecutive years, 2014-15 and 2015-16.

Molecular characterization of newly collected lac insects: Lac insect samples collected from Manipur, Nagaland, Assam on different host plants were characterized using *cox1* marker. For characterization of housekeeping genes, DNA was isolated from lac insects and amplified with cytochrome oxidase gene specific primers. The amplified products were checked on 1% agarose gel and sent for sequencing.

RESULTS AND DISCUSSION

Lac host plants: Seven states *viz.,* Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura, covering 30 districts were surveyed in the peripheral areas and a numbers of host plants were observed (Table 1). Lac host plants *viz., Acacia auriculiformis* Benth*., Albizia saman* (Jacq.) Merr*., B. monosperma, C. cajan, Calliandra surinamensis* Benth*., Ficus religiosa* L*., Grewia multiflora* Juss*., Jacaranda mimosifolia* D. Don*, Leea crispa* L*., Malvaviscus arboreus var. penduliflorus* (DC.) Schery*,*

Table 1. Lac host plants/ floral diversity in North East India during survey

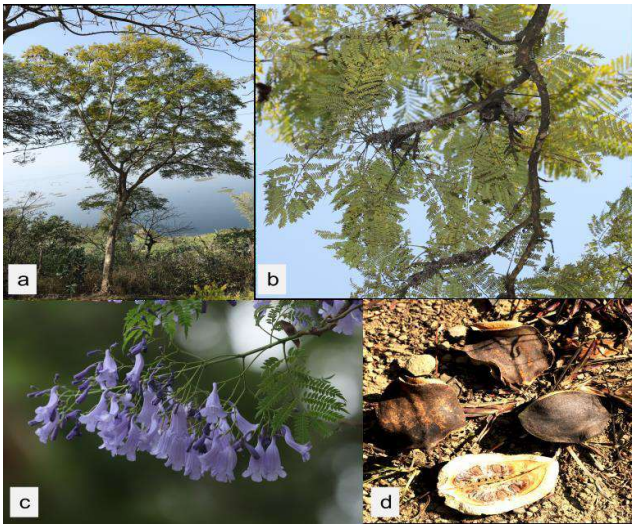
Place (State)	Lac host plants	Year
Imphal (West), Bishnupur, Churandpur, Senapati and Ukhrul (Manipur)	*Acacia auriculiformis, Cajanus cajan, Calliandra surinamensis, Ficus religiosa, Malvaviscus penduliflorus, Mallotus philippensis* and *Ziziphus mauritiana*	November 2009 and February, 2013
Dhalai, Sipahijala, Khowai, gomati, Unakoti, North Tripura, South Tripura and west Tripura (Tripura)	*A. auriculiformis, Albizia saman, A. lebbek, Ficus* spp, *Peltophorum ferrugenium* and *Z. mauritiana*	November 2010
Aizawl, Champhai &Kolasib (Mizoram)	*A. auriculiformis, A. saman and A. lebbek*	November 2010
Dispur, Marigaon, Nagaon, Kharbiolong, Diphu & Golaghat (Assam)	*A. auriculiformis, Butea monosperma, A. lebbek, Albizia lucida, A. saman, C. cajan,Ficus sp, M. penduliflorus* and *Z. mauritiana*	October 2013
Dimapur, Wokha (Nagaland)	*A. lebbek, A. saman, C. cajan Ficus sp,* Litchi*, M. penduliflorus,* Tokho, Tsolong and *Z. mauritiana*	October 2013
Ribhoi, Shillong (Meghalaya)	*C. cajan, Ficus* sp *M. Penduliflorus* and *Sohtharnu*	October 2013
Guwahati, Goalpara (Assam)	*Z. mauritiana, A. lebbek, A. saman, Ficus sp, B. monosperma, P. ferrugineum* and *A. auriculiformis*	October 2014
West Garo, East Garo hills (Meghalaya)	*Z. mauritiana, Ficus sp,* Litchi*, G. multiflora, C. cajan* and *Leea crispa*	October 2014
West Tripura, Khowai, Unokoti, North Tripura, Dhalai, Gomati, South Tripura and Shipahijala. (Tripura)	*A. saman*, *P. ferrugenium Ficus* spp*, Z. mauritiana M. philippensis, C. cajan* and *M. penduliflorus*,	October 2016
West Siang, Siang, Upper Subansiri, Lower Siang and surrounding hilly areas in Arunachal Pradesh	*L. crispa*, *Ficus semicordata, Z. mauritiana, A. saman, F. bengalensis*, and *F. religiosa*	November, 2018
Lokhtak lake, Imphal (Manipur)	*J. mimosifolia*	February, 2020

Mallotus philippensis (Lam.) *Müll. Arg., Litchi chinensis* Sonn., *Peltophorum pterocarpum* (DC.) Backer ex K. Heyne and *Ziziphus mauritiana* were observed in surveyed areas of North east India. Some of the lac host plants *viz*., *C. cajan, G. multiflora, J. mimosifolia, L. crispa, M. penduliflorus, M. philippensis, L. chinensis, are* very specific to surveyed areas of the NE states of India. *Among these, M. penduliflorus, M. philippensis* and *J. mimosifolia* were recorded as new lac insect host plants in Manipur (Fig. 1), apart from these lac host plants, *Macaranga denticulate* (Chhagru), *Kydia calycina*. (Boldubak) and the perennial red gram variety were also collected during the survey and added to our lac host plant gene bank at ICAR- NISA, Ranchi. Major lac host plants, *viz*., *S. oleosa*, *B. monosperma and Z. mauritiana* were found in Jharkhand, Chattisgarh, Odisha, West Bengal, rain tree in southern parts of India (Mohanasundaram et al 2018) and *Ficus* spp in Rajasthan, Haryana (Meena et al 2020). *M. arboreus var. penduliflorus* is cultivated in ornamental, flowers used for worship and distributed throughout India. *M. arboreus* cav. is a perennial plant belonging to Malvaceae family, having culinary and medicinal properties. It is an erect, deciduous herb or shrub, commonly known as Turk cap or sleeping hibiscus as its flowers never fully opens. *M. penduliflorus* identified as a promising lac host for *K. chinensis* (Mohanasundaram et al 2022). *M. philippensis* belongs to the family Euphorbiaceae. The kamala tree is found throughout India and in use as a medicinal tree in India for ages. The tree can grow up to 10 meters tall. Alternately arranged, ovate or rhombic ovate leaves are rusty-velvety. Male and female flowers occur on different trees. Female flowers are borne in lax spike like racemes at the ends of branches or in leaf axils. Three male flowers occur together in the axils of small bracts. The capsule is trigonous-globular, covered with a bright crimson layer of minute, easily detachable reddish powder. Kamala is the source of Kamala dye, which is used in coloring silk and wool and an antioxidant for ghee and vegetable oils. Oil is used as a hair-fixer and added to ointments. Seed oil is used in paints and varnishes. Seed cake is used as manure. (Web reference Flowers of India). *J. mimosifolia* comes under the family: Bignoniaceae. It is a magnificent deciduous tree with its clusters of fragrant blue trumpet-shaped blooms. In April the entire leafless tree is covered with blue flowers, turns the ground below into blue carpet. It is a very popular tree among gardens and along roadsides as an ornamental tree. He bark is brownish and peeling off in small thin flakes. The foliage of jacaranda consists of fern-like bipinnate compound leaves, leaflets 12-20 pairs per pinnae, narrowly elliptic. Flowers appear from March to April, in terminal racemose panicles, and bluish in colour. Fruits appear from April to May, ellipsoid-orbicular in shape and woody in nature. Origin of this tree is South America. *J. mimosifolia* was first reported as lac host for *rangeeni* strain of *K. lacca* Kerr. by Kapur in 1954 from Jamshedpur, India and lac encrustation on this tree was sparse to moderately thick. Later on was able to successfully infect lac on Jacaranda at ICAR-NISA (Lohot et al 2020).

Lac insect and associated fauna: A natural infestation of the lac insect was on different host plants, viz., *C. cajan*,

Malvaviscus penduliflorus a) Plant b) Lac encrustation

Mallotus philippensis a)Tree b) Bark c) Seeds d) Lac encrustation



Jacaranda mimosifolia a) Tree; b) Lac encrustation; c) Flowers; d) Pods with seeds

Fig. 1. New lac insect host plants discovered in Manipur

Ficus spp, *G. multiflora*, *J. mimosifolia*, *L. chinensis*, *M. penduliflorus*, *M. philippensis, and Z. mauritiana*. Lac encrustation covered with an ant nest made of mud slurry was observed on *M. penduliflorus* and *M. philippensis* at Manipur. This was a very peculiar characteristic, i.e., the symbiotic relationship between lac insects and ants. Ants are fed on honey dew secreted by lac insects, and lac insects protect the ants from parasitoid and predator attack. Lac insect collected from Manipur on *M. penduliflorus* was new species, *Kerria manipurensis* (Ahmad et al 2013). Collected ant species were also identified as *Crematogaster flava Forel, Crematogaster rogenhoferi Forel, C. rothneyi Forel,* and *Technomyrmex albipes Smith.* No lac insect species was observed in surveyed districts of Mizoram and Tripura probably due to high rain fall and humidity throughout the year in these states. Lac insect parasitoids, (*Aprostocetus purpureus* Cam.*, Tachardiaephagus tachardiae,* How.) and predators (*Pseudohypatopa pulverea,* Meyr., *Eublemma amabilis* Moore) were also recorded from the collected lac insect samples (Table 2, 3).

Similar survey work was reported by various authors in different parts of the country, incidence of a lac insect was observed infesting *arhar* (*C. cajan*), *peepal* (*F. religiosa*) and *champak* (*Michelia champaca*) at Nongmeibung, a locality in Imphal East District at Manipur (Devjani and Singh 2012). Lac insect along with more ants but without nest was found on the ornamental plant, *Amherstia* nobilis, in Kerala. Natural infestation of lac insect covered with wax secretions was found *A. saman* and *F. religiosa* in Tamil Nadu (Mohanasundaram et al 2018). Naturally occurring lac was found in large quantities on *peepal* and Litchi tree during the survey period of 2017 and 2018 in Assam (Anonumous 2018). *Ficus* and *M. penduliflorus* are the most productive hosts in Manipur; Litchi in Nagaland, Arunachal Pradesh and Mizoram and *Ficus* in Meghalaya (Sigh et al 2020). Good encrustation of lac was seen on *A. auriculiformis*, *Annona reticulata*, *Calliandra calothyrsus*, *Ficus religiosa*, *F. racemosa*, *F. tsiela*, *Peltophorum ferrugineum*, *Pithecellobium dulce* and *Samanea saman in the* western plains of India (Meena et al 2020). *Ficus spp., Z. mauritiana, A. saman, and B. monosperma are the important host plants throughout India for the naturally occurring lac insect. (*Monobrullah and Kishor 2020, Gupta et al 2020, Bhatnagar et al 2022)

Biological attributes: Evaluation of four lac insect stocks

Table 2. Lac insects in North East India during survey

Place (State)	Host plant	GPS	Date of collection	Remarks
Imphal West (Manipur)	*M. penduliflorus* *C. cajan* *M. philippensis*	*M. penduliflorus* : 24° 44.727'N 093°49.394'E and elevation 771m *C. cajan*: 24° 44.751'N 093°49.350'E and elevation701m *M. philippensis* : 24° 44.813'N 093°49.194'E and elevation 751m	06-02-2013	Live, mature and crimson coloured lac insect at Heigrujam
	Z. mauritiana	Patsoi: 24° 47.710'N 093°52.520'E and elevation 776m Khaidem : 24° 45.084'N 093°49.797'E and elevation 770m Khumbong : 24° 46.341'N 093°49.994'E and elevation 771m	06-02-2013	Live, mature and crimson coloured lac insect at Patsoi, Khaidem and Khumbong
	F. recemosa	24° 46.336'N 093°49.971'E and elevation 782m	06-02-2013	Live, mature and crimson coloured lac insect at Khumbong and Near PWD, Imphal
	J. mimosifolia	24° 31.05'N 093°47.41"E and elevation 778m	04-02-2020	Live, immature lac insect at Sendra Park, Lokhtak lake, Imphal
Bishnupur, Manipur	*M. penduliflorus*	Tronglaobi : 24° 28.707'N 093°45.119'E and elevation 793m Kwatha : 24° 26.660'N 093°43.638'E and elevation 799m Naranseina : 24° 31.159'N 093°45.417'E and elevation 770m	07-02-2013	Live, mature and crimson coloured lac insect at Tronglaobi, Kwatha and Naranseina
Dimapur, Nagaland	*L. chinensis*	25° 45' 24" N 93° 50' 20" E and elevation 295 m	21-10-2013	Live, immature and crimson coloured lac insect at ICAR NEHR RC, Jarnapani
Wokha, Nagaland	*Z. mauritiana*	26° 09' 24" N 94° 00' 54" E and elevation 241 m	23-10-2013	Live, mature and crimson coloured lac insect at Lio Wokha Old
Karbi Anglong, Assam	*F. religiosa*	26° 12' 55" N 93° 34' 31" E and elevation 970 m	25-10-2013	Live, mature and crimson coloured lac insect at Doloigaon
Ri-bhoi, Meghalaya	*Ficus spp*	25° 54' 03" N 92° 08' 17" E and elevation 783 m	27-10-2013	Live, mature and crimson coloured lac insect at Sonidan
West Garo Hills Meghalaya	*C. cajan*, *L. chinensis*, *G. multiflora*	Bawegre : 25° 41' 01" N 90° 22' 09" E and elevation 634 m Tapragre : 25° 40' 43" N 90° 20' 55" E and elevation 708 m Chiokgre : 25° 41' 13" N 90° 21' 17" E and elevation 674 m	10-10-2014	Lac insect (Mature) at Bawegre; Tapragre and Chiokgre

collected from the NEH region (Assam, Manipur, Meghalaya, and Nagaland) was carried out during summer season crop in two consecutive years, 2014-15 and 2015-16 on *F. macrophylla*. Pre-harvest parameters, *viz*., settlement density, initial mortality, and sex ratio, were studied. Average settlement density was 51.4 per sq cm, with 26.59 per cent mortality and 100 per cent male population recorded. Subsequent observations could not be taken from Manipur stock due to 100 per cent male lac insect populations. The summer generation normally contains higher proportion of males. The average density of settlement ranged from 61.42 to 68.96 per sq cm, with 13.22 per cent significantly lower mortality on Nagaland stock. The male/female ratio was higher than optimal in all three stocks, ranging from 62 to 79 per cent. Postharvest parameters, *viz*., fecundity, cell number, and resin weight, were also studied. Average fecundity was significantly higher at 290.35 numbers in Assam stocks, with no significant difference in cell weight or resin weight from all three stocks (Table 4). Evaluation of lac insect stocks collected from the NEH region (Assam, Meghalaya, and Nagaland) was continued during *katki* (rainy season) crop during 2015 and 2016. Average settlement density was significantly higher (120.55 per sq cm) with less initial mortality (7.12 per cent) in Meghalaya stock. On all stocks, the male/female ratio ranged between 46.46 and 51.28 per cent. Average fecundity, cell weight and resin weight were not significantly different among the three stocks (Table 5). Assam stock was showed more potential for the *rangeeni* summer season crop, whereas Meghalaya stock indicated more potential for the *rangeeni* rainy season crop. In both seasons, there was a high average density of settlement with low mortality in both stocks (Assam and Meghalaya). In cell weight and resin weight, no significant difference was observed among the stocks studied. Although there is no significant variation observed, further intensive studies may be required to identify the best performing line. Rahman et al (2021), studied productivity linked parameters and the life cycle of the lac insect, *K. chinensis,* on eight different lac hosts: *Flemingia semialata* Roxb.*, Flemingia strobilifera* (L.) W.T.Aiton*, Indigofera teysmannii* L.*, F. religiosa, Z. mauritiana, Litchi chinensis* Sonn.*, Hibiscus rosa-sinensis* L. and *C. cajan.* Among the eight lac hosts, the highest density of crawler settlement with the lowest mortality, the maximum cell weight and fecundity were recorded on *F. semialata*.

Molecular analysis: Lac insects collected from Manipur on *Z. mauritiana* tree revealed 97% homology with both LIK31 and LIK23 (both *K. chinensis* lines). Lac insects collected from *F. religiosa* were found to have 90% homology with LIK31 and 89% with LIK23. Lac insects collected from *M. penduliflorus* from Imphal West, Manipur showed 97% homology with both LIK31 and LIK23. The cox1 product of lac insects collected from *Malvaviscus* from Bishnupur, Manipur showed 98% homology with both LIK31 and LIK23. In case of

Table 3. Lac associated faunal diversity in North East India during survey

Place (State)	Host plant	Lac associated fauna
Lio wokha old Nagaland	*Z. mauritiana*	Nil
Sonidan, Meghalaya	*Ficus sp*	*Aprostocetus purpureus, Eublemma amabilis*
Doloigoan, Assam	*Ficus sp*	*A. purpureus, Pseudohypatopa pulverea, E. amabilis*
Jarnapani, Nagaland	*Litchi*	*Tachardiaephagus tachardiae*
Heigrujam, Manipur	*M. penduliflorus*	Nil
Imphal West, Manipur	*M. penduliflorus*	*Crematogaster flava, C. rogenhoferi, C. rothneyi* and *Technomyrmex albipes*

Table 4. Biological parameters of lac insect collected from NEH region of India during summer season crop during 2014-15 to 2015-16 (Pooled)

Name of the lac insect stock	Pre-harvest productivity parameters			Post-harvest productivity parameters		
	Settlement density (Nos. / cm^2)	Initial mortality (%)	Sex ratio (% Male)	Fecundity (nos./Female)	Cell weight (mg)	Resin weight (mg)
Assam	68.96 (8.30)	19.41 (4.38)	62.43 (7.88)	290.35 (17.02)	12.19 (3.49)	10.49 (3.24)
Meghalaya	61.42 (7.82)	28.60 (5.34)	77.09 (8.77)	253.01 (15.89)	11.83 (3.44)	9.84 (3.14)
Nagaland	66.48 (8.11)	13.22 (3.62)	79.17 (8.90)	229.85 (15.13)	12.54 (3.54)	10.06 (3.17)
CD (p=0.05)	NS	0.361	0.342	1.20	NS	NS

*Figures in parentheses are square root √ (X+0.5) transformation values; Means are significant at p< 0.05

lac insects collected from *M. philippensis* there was 97% homology with both LIK31 and LIK23. Lac insects collected from Nagaland (on *L. chinensis)* revealed 95% homology with both LIK31 and LIK23. Lac insects collected from Assam (on *F. religiosa*) showed 99% homology with LIK31 and 98% with LIK23 (Table 6). All of our collections from NEH region matched with *K. chinensis* lines. *K. chinensis*is also having peculiar characteristic i.e the aleuritic acid content was maximum 19.81 per cent with 98.78 per cent purity (Ali *et al*. 2021). Mohanasundaram et al (2018) earlier study found that the molecular analysis based on the COX1 sequence classified the collected lac insects from Tamil Nadu and Kerala under the *Rangeeni* strain clustered with *K. lacca* in the phylogenetic tree.

Indigenous Technical Knowledge

Lac insect and its products: Indigenous Technical Knowledge (ITK) information related to lac was also collected from North East India during the survey. Bamboo cages and Banana leaves are used for collection, carrying and inoculation of lac insect broodlac and preservation of broodlac, respectively; during lac production operations. Scraped lac is used for fixing *dauli (long sickle)* at ChiokTferagre, West Garo Hills district in Meghalaya. Lac is also used as curative medicine against rheumatic and other body pain in East Karbi Anglong district and against itching at Merapani, Golaghat district of Assam. Lac dye is used for coloring Eri silk cloth at Umsning, Ri-Bhoi district, Meghalaya.

Bamboo cage: Bamboo nodes are made into a cage-like structure. This bamboo cage is being used for collecting and carrying the lac insect brood. It is used to avoid the falling of broodlac and easy *phunki* collection.

Banana leaves: Banana leaves are cut according to the broodlac quantity. Broodlac is kept inside the banana leaves before folding and tying the banana leaves along with the broodlac, then keeping the folded banana leaves containing the broodlac above a wet place at home. When the crawler's emergence starts, broodlac will be used for inoculation. It is used to preserve broodlac for further inoculation.

Lac resin and Lac dye at West Garo Hills, Meghalaya: The lac insect was collected or harvested from the lac host trees. Afterwards, scrapped lac was taken, and the same was washed with water to remove the lac dye. The lac dye was then used to colour Erisilk cloth. In this process, lac resin was separated out and melted by heating. That lac resin was used to fix the sickle and fix the iron blade in the bamboo to make *dauli* (*long sickle*).

Lac cell in East Karbi Anglong district of Assam: Approximately one gram of fully matured lac cells are taken and put the pre-weighted lac cells in a bamboo pot / pipe. A glass of water is added to the bamboo pipe. The mixture is boiled under high flame till lac cell completely is dissolved in

Table 5. Biological parameters of lac insect collected from NEH region of India during rainy season crop during 2015 to 2016 (Pooled)

Name of the lac insect stock	Pre-harvest productivity parameters			Post-harvest productivity parameters		
	Settlement density (Nos. / cm^2)	Initial mortality (%)	Sex ratio (% Male)	Fecundity (nos./Female)	Cell weight (mg)	Resin weight (mg)
Assam	85.87 (9.22)	7.50 (2.73)	46.46 (6.79)	241.00 (15.51)	20.92 (4.55)	17.46 (4.15)
Meghalaya	120.55 (10.95)	7.12 (2.62)	51.28 (7.15)	277.17 (16.60)	24.87 (4.98)	20.43 (4.51)
Nagaland	79.08 (8.85)	15.04 (3.87)	49.65 (7.04)	256.86 (16.01)	21.55 (4.64)	18.18 (4.25)
CD (p=0.05)	1.15	0.46	NS	NS	NS	NS

*Figures in parentheses are square root √ (X+0.5) transformation values; Means are significant at p< 0.05

Table 6. *cox1* based sequence homology of newly collected lac insect samples

Location	Host plant	Code	Product length (bp)	% Homology	Matching with
Assam	*Ficus religiosa*	AsA1	530	99/98	LIK0031/23
Manipur	*Z. mauritiana*	MaB	517	97	LIK0031/23
Manipur	*F. religiosa*	MaF	583	90/89	LIK0031/23
Manipur	*Hibiscus*	MaH	598	97	LIK0031/23
Manipur	*Malvaviscus*	MaM	594	98	LIK0031/23
Manipur	*M. philippensis*	MaU	594	97	LIK0031/23
Nagaland	*Litchi chinensis*	NL1	510	95	LIK0031/23

water, and then the total volume of the mixture to be reduced to a quarter of the initial volume under low flame. The content is kept aside for cooling under shade. Finally, the mixture is divided into three parts and one part may be taken a day against rheumatic and other body pain. The actual amount to be administered may vary according to the body weight and intensity of pain. Lac encrustation is boiled in water; allowed to cool, and the extract is applied to the body to soothe itchy skin.

CONCLUSION

ICAR-NISA, Ranchi has a mandate of collection and conservation of lac insects of the country and implements through network mode (All India Network Project on Conservation of Lac Insect Genetic Resources (NPCLIGR)). Lac insect is primarily cultivated in Jharkhand, Chhattisgarh, Odisha, and West Bengal in scientific manner. In the past, lac insect cultivation was prevalent in some places of the NEH region. But today it is not popular because of unawareness of scientific lac cultivation methods and natural lac resin is being replaced by synthetic ones. The present study revealed that there is vast diversity in lac host plants and lac insects which are specific to NEH region. It is envisaged that the distinct lac insects and host *species* would be valuable in developing new lac insects + host plant combinations for enhancing the lac productivity of the NEH region. Appropriate conservation initiatives are also needed for conserving the valuable lac-associated faunal and floral diversity in NE region. Plenty of lac-based ITKs are also available which are not well documented and should be evaluated scientifically and promoted among the lac growers. Awareness should be created among the lac growers as well as in the general public about the values, advantages, and usage of natural products with regards to lac insect products.

AUTHOR CONTRIBUTION

Dr. A. Mohanasundaram: survey, lac insect maintenance, biological characterization of lac insect, experimental design, data analysis, manuscript writing. Dr. K.K Sharma: Lac insect maintenance, guided in the experimental plan, manuscript writing. Dr. T. Kandasamy: Molecular characterization of lac insect, experimental design and editing of manuscript, Dr. V.D. Lohot: Survey, Lac host maintenance, experimental design and editing of manuscript. Dr. J. Ghosh: Survey, Lac host maintenance and experimental design. Dr. P. Das: ITK's of lac insect and its products and editing of manuscript.

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Assessment of Low-Cost Filter Material for Rooftop Rainwater Harvesting Structure

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Abstract: RRWH is the technique through which rainwater is captured from the roof catchments and directed to groundwater. The present study focused on to design low-cost filter material for rooftop rainwater harvesting structure (RRWH) for groundwater recharge. Three technology options (TO) with different filter viz. TO-I (2 meter boulder + 0.5 meter stone + 0.5 meter sand), TO-II (1 meter boulder + 1 meter stone + 0.50 meter sand fill with bottle + 0.5 meter sand), and TO-III (1.5 meter boulder + 1 meter stone + 0.5 meter charcoal + 0.5 meter sand) were evaluated at six locations for comparative performance of these filters during the pre and post monsoon of year 2019 and 2020. Pooled analysis of both the year shows that about 83-97% of roof water passes through the filter which designates a very good and satisfactory performance. Post monsoon study after the installation of RRWH structure revealed that during the year 2019 the water table uplifted from 5.9 to 3.76 meters while during the year 2020, the water table raised from 5.41 to 2.89 meters. Among all the technology options used the filter of TO-II was found to be best in respect of infiltration rate, cost and overall performance. Therefore, the adoption of this technique at mass level with community participation could help in getting the significant results to mitigate the water requirement.

Keywords: Filter, Groundwater recharge, Infiltration rate, Roof Top Rainwater Harvesting, Water table

Conservation and management of water, is essential for sustainable development of any region (Santhoshi and Kumar 2021). The proper augmentation and management are needed through proper planning in groundwater resource development and management (Ayyandurai and Venkateswaran 2021). Groundwater and surface water may be unavailable for drinking water in numerous cases. The groundwater level may be too deep, contaminated with minerals and chemicals such as arsenic or salt as well as surface water may also be contaminated with faces or chemicals. In these cases, rainwater harvesting can be an effective and low-cost solution to resolve the above problems (Li et al 2000, Jothiprakash and Mandar 2009). Singh et al (2021) suggested that the use of fertilizer and crop manure in the fields should be reduced to sustain the water quality parameters. The good thing about rainwater is that it falls on your own roof, and is almost always of excellent quality. Several studies have shown that water from well-maintained and covered rooftop tanks generally meets drinking water quality standards. Roof rain water harvesting systems can be implemented to any type of roof constructed materials, but some material has high efficiency on collecting rain water from the roof, with less retention and evaporation at the roof (Hofman and Paalman 2014). It can be applied as a successful urban storm water management or flood mitigation method. This method also reduces surface runoffs in to the urban sewage system, control peak load and overload of the system, and therefore minimizes water borne diseases (Ranasinghe and Dissanayake 2019). This method is less expensive and very effective if implemented properly for augmenting the groundwater level of the area.

Rooftop rain water harvesting can be established at any building, it can be large or small, where each of the parts contributes to RWH structure. The RWH system mainly consists of catchment area, transportation, flushing and filter media like sand gravel filter, charcoal filter etc. Rooftop Rain Water Harvesting is the technique through which rain water is captured from the roof catchments and recharge to groundwater (Kumar et al 2011, Awuah et al 2014, Krishnaveni and Vighnesh 2016). RRWH is made of roof catchment, down pipe, first flushing pipe and filter unit. The dipping groundwater levels and deterioration in its quality in some districts of Bihar over the past two years have become a cause of worry for the state authorities. Previous year, most of the place in the state recorded low rainfall during monsoon season. Out of 534 blocks of Bihar, 280 blocks have been

declared as agricultural drought prone area as per weather parameter in the state. In the Muzaffarpur district, many villages and panchayat faced water crisis problems due to decrease of groundwater level. Pre experimental survey revealed that in last few years water level has depleted by 10-12 feet in most part of the study area. The best method of recharge through rainwater is to keep earth clean and to prevent entry of garbage into the capacity tank which can be achieved by using quality filter materials (Pandey et al 2003). Bihar is agriculture dominant state and most of farmers having marginal and small land holdings henceforth, establishment of low-cost filter for rooftop rainwater harvesting structure would be economically feasible for groundwater development. In view of above facts, the present study has been carried out to prepare low-cost filter for rain water harvesting structure and assess the comparative performance of filter unit.

MATERIAL AND METHODS

Study area: Muzaffarpur district of Bihar covers an area of 3172 sq. km, between latitudes 25°53'52.475"N to 26°15'33.053"N and longitudes 85°43'15.814"E to 84°52'6.792"E. An average annual rainfall of the study area is 1145 mm. The area receives more than 85% rainfall during monsoon season (July-September). The altitude of the Muzaffarpur district varies from 58 m to 62 m above mean sea level (MSL). Soil texture in the study area is sandy and sandy loam. The average monthly weather data for six consecutive years from 2015 to 2020 have been presented in Table 1.

The experiment was conducted at six different locations namely Bhagwatpur, Dawarikanathpur, Bhatoliya, Gobindpur and KVK Saraiya campus across two block of muzaffarpur district during the year 2019 and 2020. Each technology options viz. TO-I, TO-II and TO-III have been installed at two different sites (Table 2).

Methodology for planning and design: Pre experimental field survey was conducted to gather the key information by interacting with local people and the acquired information has been employed to conduct the experiment. Groundwater information was collected from Central Ground Water Board (CGWB) website. The data were utilized for site selection of

Table 1. Monthly average weather parameter for the year 2015 to 2020

Month	Temperature (^{0}C)		Humidity (%)		W/S (km./hr)	Rainfall (mm)	Evaporation (mm/day)
	Maximum	Minimum	Morning	Evening			
January	22.8	8.1	85	56	2.4	1.2	1.7
February	25	10.7	84	55	5.2	25.4	2.4
March	30.3	13.5	75	44	2.9	4.2	4.4
April	34.7	21.4	76	51	3.8	7.6	6.1
May	39	24.7	77	50	5.6	14.4	6.6
June	37.5	26.5	80	59	6.7	30.4	5.5
July	33.2	26.1	88	73	6.4	354.0	3.7
August	34.3	26.8	89	75	5.1	171.7	5
September	31.4	25.2	91	80	5	403.0	2.7
October	29.3	22.1	92	82	0.5	6.6	2.7
November	28.4	16.6	93	68	0.9	0.0	1.9
December	21	9.7	92	75	0.2	22.0	1.0

Source: RPCAU, PUSA, Samastipur, Bihar

Table 2. Location of rainwater harvesting structure

Village	Technology option	Block	Latitude	Longitude
Bhagwatpur (Site-a)	TO-I	Madwan	26° 5'5.42"N	85°13'18.99"E
Dawarikanathpur-A (Site-b)	TO-III	Madwan	26° 4'29.87"N	85°13'53.64"E
Dawarikanathpur-B (Site-c)	TO-II	Madwan	26° 4'37.17"N	85°14'16.73"E
Bhatoliya (Site-d)	TO-I	Madwan	26° 3'0.19"N	85°12'8.01"E
Gobindpur (Site-e)	TO-II	Saraiya	26° 1'52.95"N	85° 5'1.19"E
KVK Saraiya campus (Site-f)	TO-III	Saraiya	26° 1'53.15"N	85° 8'38.81"E

RRWH structure as per the previous study (Li et al 2000, Krishnaveni and Vighnesh, 2016 and Kumar et al 2011). In the study area annual average rainfall 1145 mm data was collected from Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar. Low cost filter material for RRWH structure design methodology was adopted in the present study (Fig. 1).

The catchment area of each site of the roof was calculated by field visit. The total rainwater collected for rainwater harvesting purpose was estimated using rational formula (Awuah et al 2014, Krishnaveni and Vighnesh 2016).

Q = CIA

Where, Q= Peak surface runoff, m^3/s,

C= A runoff coefficient that is the ratio between the runoff volume from an area and the average rate of rainfall depth over a given duration for that area which can varied from 0.8-0.9 in tiles and 0.7-0.9 in corrugated metal sheet .

I= average intensity of rainfall in inches per hour for a duration equal to the time of concentration, T_c, m/s, A= Area, m^2.

Based on runoff coefficient and rainfall intensity, peak runoff discharge was estimated using above equation and the data was utilized for designing RRWH structure. All calculations related to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, infiltration, catchment surface wetting and evaporation, which contributes to reduce the amount of runoff.

Filter material: The three different filtration techniques were used to set up unit of groundwater recharge structure (Table 3). Distinguish depth of different layer was maintained through filter material layers of boulder, stone, sand, bottle filled with sand and charcoal (Fig. 3). There are numerous contaminants (leaves, fledgling droppings, dust etc.), which may get mixed up with this unadulterated water on the rooftop was shifted away before the water enters into the groundwater recharge unit.

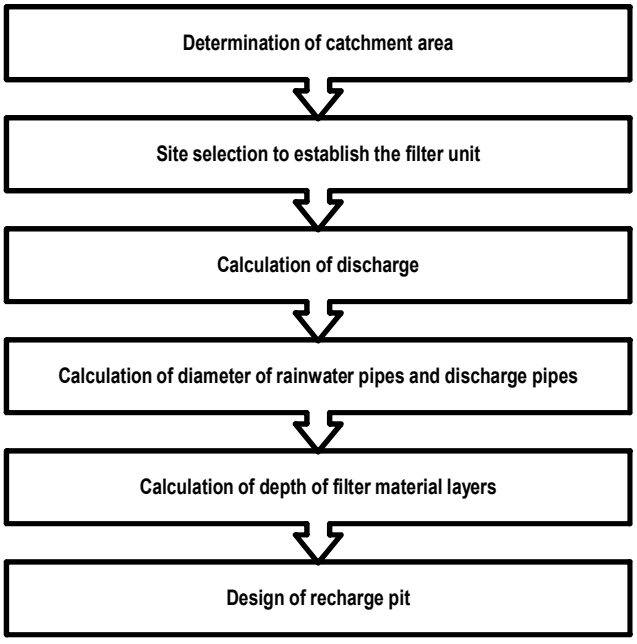

Fig. 1. Fow chart for RRWH structure

RESULTS AND DISCUSSION

The set of parameters were chosen to be the most influential ones to determine the feasibility of RRWH structure (Table 3). Filter unit has been designed by considering the values of parameters viz. roof area, rainfall and filter capacity of water before filtration. The key component of this design is the filter media, where the better result through filter will make the study convenient for groundwater recharge and storage tanks. Since the site is in rural area the natural organic material will be easily available for the purpose of filter unit materials such as boulder, stone, sand fill with bottle, coal, fine sand etc. So, an efficient and economical filter can be designed which is feasible to implement anywhere as filter media, for the construction of RRWH structure. Filter capacity was assessed by peak discharge (m^3/sec) based on rainfall intensity, coefficient of runoff and catchment area of structure. The pooled data of two locations of peak discharge for roof catchments during the year 2019 for TO-I, TO-II and TO-III respectively was calculated as 1 , 0.74 and 1.05 l/s whereas, these for the year 2020 was 1.40 1.03 and 1.45 l/s (Table 4, 5). However, the peak discharge per unit area for all the technology options was statistically at par due to similar rainfall intensity, runoff coefficient for similar roof surfaces received across all the roof catchments. The variation might be due to different roof catchment area taken under the study.

Filter plays a significant role while constructing RRWH system designed for direct use of water, this acts like the heart as in a human body. Once the water enters into this filter, passes through different layers of filter material and recharge to groundwater. About 5-10% of water, depending on the intensity of rainfall, gets rejected by the filter. Pooled analysis of both the year shows that about 83-97% of roof water passes through the filter which designates a very good and satisfactory performance. Maximum filter recharge received through TO-II (95 to 97 %) followed by TO-I (90 to 95 %) and TO-III (83 to 85 %). The highest filter recharge rate during both the year was observed in TO-II (17.12 mm/hr and 19.45 mm/hr) followed by TO-I and TO-III (Table 6). The water reaches the roof to filter tank possesses some finer dust particles, which can be removed by the filter. During first 5-10 minutes of rain, amount of water rejected is more due to high

dirt-load in the first-flush water in the downside filter layer was also noticed. However, the new filter is really maintenance-free and there is no need for manual operation to divert the first-flush but such filters require change of upper layer only i.e. sand before rainy season with the help of one mesh. Mostly such systems require a provision for 'First-Rain' to prevent entry in the filter. One control valve is provided in the filter for draining out of first rainfall. Study on assessment of different types of filters for RRWH structure has not been so far done but designing of low cost RRWH structure and its importance has already been discussed earlier by researchers (Pawar et al 2014, Jain et al 2015, Gohel et al 2020, Mishra et al 2020, Himantha et al 2021, Sahu et al 2023).

The pre survey showed that water table before monsoon during 2019 and 2020 was 5.9 and 5.41meters respectively. Post monsoon study after the installation of RRWH structure revealed that the water table uplifted from 5.9 to 3.76 meters (56.91 %) during 2019 and 5.41 to 2.89 meters (87.19%) during the year 2020. The highest groundwater recharge has been achieved during the year 2020 due to high rainfall intensity as compared to year 2019. The maintenance cost of all filters was almost zero and before onset of monsoon, they only need to change the upper layer of filter that is sand. The filter technique used in TO-II was found to be best among all the technology options under study due to its higher infiltration rate, low cost and overall performance (Table 6). Different approaches have proven the economic viability of

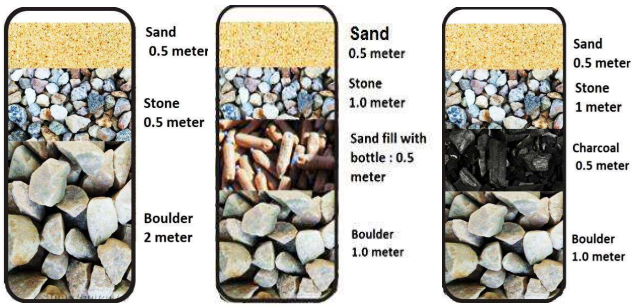

Fig. 2. Construction of different types of filter material used for RRWH

Table 3. Rainwater harvesting filter techniques

Technology option (TO)		Details
TO-I	:	Filter depth: Boulder 2 meter, 0.5 meter stone, Sand 0.5 meter
TO-II	:	Filter depth: Boulder 1.0 meter, stone 1 meter, sand fill with bottle 0.50 meter, Sand 0.5 meter
TO-III	:	Filter depth: Boulder 1.5 meter, stone 1 meter, charcoal 0.5 meter, Sand 0.5 meter

Table 4. Computation of peak discharge (m^3/s) using rational formula for different RRWHS (2019)

Technology option	Coefficient of runoff (C)	Rainfall intensity (mm/hr)	Roof area (m^2)	Peak discharge (m^3/s)	Peak discharge (l/s)
TO-I	0.8	18	313.0	0.001252	1.00
TO-II	0.8	18	232.0	0.000928	0.74
TO-III	0.8	18	327.5	0.001310	1.05

Table 5. Computation of peak discharge (m^3/s) using rational formula for different RRWHS (2020)

Technology option	Coefficient of runoff (C)	Rainfall intensity (mm/hr)	Roof area (m^2)	Peak discharge (m^3/s)	Peak discharge (l/s)
TO-I	0.8	20	313.0	0.0013915	1.40
TO-II	0.8	20	232.0	0.0010310	1.03
TO-III	0.8	20	327.5	0.0014555	1.45

Table 6. Comparison of treatment options for filter performance

Technology options	Maximum rainfall intensity (mm/hr)		Filter recharge rate (mm/hr)		Source of power	Cost	Maintenance	Overall performance
	2019	2020	2019	2020				
TO-I	18	20	16.20	18.45	Gravity	Medium	All filters require change upper layer of filter (sand) before rainy	Good
TO-II	18	20	17.12	19.45	Gravity	Low		Very Good
TO-III	18	20	14.94	17.13	Gravity	High		Good

the RWH through cost-benefits analysis, net present values, and internal rate of return (Hofman and Paalman, 2014).

CONCLUSIONS

Filtration unit is the important component for deciding low-cost filter for rooftop rainwater harvesting structure (RRHS). Filter materials used for filter plays an important role for recharging the structure. All the location selected for the study showed similar rainfall intensity. However, due to change in roof area a variation of peak discharge in the study area was observed. Filter recharge rate was highest in case of TO-II (Filter depth: Boulder 1.0 meter, stone 1 meter, sand fill with bottle 0.50 meter, Sand 0.5 meter) and followed by TO-I (Filter depth: Boulder 2 meter, 0.5 meter stone, Sand 0.5 meter) TO-II filter was best and efficient due to its high recharge rate. Only the upper layer of filter needs maintenance in TO-II which reduces the overall cost and hence found most economical among all filter. All the authors gratefully acknowledge ATMA, Muzaffarpur, of Government of Bihar, for providing financial support, to complete this research.

AUTHORS CONTRIBUTION

Tarun Kumar: Conceptualization, conduct of experiment, data collection , Nidhi Kumari and Prabhat Kumar Singh: Data curation, writing original draft, validation, Anupma Kumari and Jitendra Prasad: review & editing

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Groundwater Quality Assessment of Nandyal district using Geographical Information System

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***Abstract*:** Nandyal district was situated on west side of Nallamala of Eastern ghats range in Andhra Pradesh. The physiography of the district acts as catchment and basin for Kundu river drain a rivulet to Penna river of Andhra Pradesh. Groundwater samples of Nandyal district were analyzed for various properties *viz.,* pH, EC, Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}; CO_3^{-2}, HCO_3^{-}, Cl^{-} and SO_4^{-2}. The pH, EC, SAR, RSC, Kelly's ratio (KR), soluble sodium percentage (SSP) and permeability index (PI) in groundwater ranged from 6.5 to 8.4, 0.2 to 22.0 (dSm^{-1}), 0.18 to 34.1 ($mmol\ l^{-1})^{1/2}$, -91.2 to 7.6 ($me\ l^{-1}$), 0.07 to 10.9, 6.99 to 88.45 and 32.79 to 110 respectively. The relative abundance of ions for most of the water samples were Na^{+}> Ca^{+2}> Mg^{+2}> K^{+} for cations and HCO_3^{-}> Cl^{-}> SO_4^{-2}> CO_3^{-} for anions. The irrigation water quality of groundwater classified as good (66.67%), marginally saline (19.75%), saline (3.29%), high SAR saline (7.41%), marginally alkali (1.65%), alkali (0.41%) and high SAR alkali (0.82%). Based on thematic maps developed using inverse distance weightage method in geographical information system, the poor quality groundwater was observed in Midtur, Nandyal, Gadivemula, Gospadu, Koilakuntla, Dornipadu, Uyyalawada, Chagalamarri, Allagadda mandals of Nandyal district.

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

Assessment of spatial variability in groundwater quality for irrigation is key for sustainable groundwater use. The quality of groundwater is dynamic and it changes with the rainfall distribution and climate change activities. Demand for groundwater has increased tremendously in recent years due to increase in population and intense agricultural activities. Good quality irrigation water helps the farmer in achieving the targeted production and with optimum input management. Spatial variability information of groundwater quality helps the farmers and other stakeholders for effective management of inputs in crop production (Vinoth Kanna et al 2020). It is essential to understand the spatial distribution of groundwater quality in order to determine its suitability for irrigation purposes. Such an assessment is helpful to understand the influence of irrigation water quality on crop productivity and to suggest agronomic practices for better crop yields by reducing the adverse effects of saline/alkaline water irrigation (Subbaiah et al 2022). Keeping this in view a study was conducted to assess the groundwater quality of Nandyal district of Andhra Pradesh state, India using Geographical information system.

MATERIAL AND METHODS

Study area: Nandyal district was situated on west side of Nallamala of Eastern ghats range in Andhra Pradesh lies in between 14°53' 18.68 " and 16° 9' 18.938" of Northern latitudes and 77° 39' 12.261" and 78° 55' 1.722" Eastern longitudes occupies central part of Andhra Pradesh. Nandyal has a total geographical area of 9681 km^2. The district is bordered by Nagarkurnool district of Telanagana state in North, east by Prakasam and on the South by Kadapa, Anantapur and west by Kurnool and district.

Methodology: Two hundred and forty three (243) ground water samples were randomly collected along with GPS coordinates from each mandal of Nandyal district (Fig. 1). Standard procedures were followed to analyze the quality of water. pH in water samples was determined by potentiometrically using pH meter. Electrical conductivity was determined by using Conductivity Bridge. Chlorides (Mohr's method), carbonates and bicarbonates (double indicator method) and calcium and magnesium (versenate method) were determined by adopting the procedures given by Richards (1954) .Similarly the sodium and potassium in ground water samples were determined by using flame photometer (Richards 1954). 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.

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.

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

Where the concentration of ions are 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

Groundwater Quality Determination

Spatial variability in water reaction (pH): The pH of water samples of Nandyal district varied from 6.5 to 8.4 with a mean of 7.26. (Table 1, Fig. 2). The highest pH (>7.6) in groundwater was in parts of Kothapalle, Gadivemula, Banaganapalle, Gospadu, Koilakuntla, Dornipadu mandals of Nandyal district.

Spatial variability in EC: The electrical conductivity of groundwater of Nandyal district ranged from 0.4 to 22.3 dS m^{-1} . Based on electrical conductivity groundwater is grouped into different classes (Table 2) *viz.,* Groundwater with <2 dSm^{-1} (72.84%), 2-4 dSm^{-1} (16.87%), 4-6 dSm^{-1} (4.94%), 6-8 dSm^{-1} (2.06%), 8-10 dSm^{-1} (1.23%) and >10 dSm^{-1} (2.06%). Highest EC (22.3 dSm^{-1}) was reported with Nandyal mandal and lowest EC (0.4 dS m^{-1}) was reported with Owk mandal. The variation in EC may be due to variation in geological conditions, soil type, drainage and climate. Groundwater salinity is observed mostly with cuddapah and Nandyal formations and in black cotton soils of eastern part of the district. Gneissic and sedimentary terrain of the district maybe the reason for the good (low saline) quality water of the district. The correlation matrix of the groundwater samples exhibits highly significant positive correlation (>0.6) between EC and Ca^{+2}, Mg^{+2} (0.867**), Na^+ (0.972**), Cl^- (0.952**) and SO_4^{-2}. The higher EC of groundwater is due to the presence of alluvial and black cotton soils might decreased the infiltration of rainwater at flood plains of Kundu river and in parts Gadivemula, Nandyal, Gospadu, Koilakuntla, Dornipadu, Uyyalawada mandals of Nandyal district (Fig. 3). The concentration and composition of ions of groundwater significantly influenced the electrical conductivity of water (Subbaiah et al 2023)

Variability in ionic concentration: The concentration of cations viz., calcium, magnesium, sodium and potassium in water samples varied from 1.2-39.6, 0-56.0, 0.26-131 and 0.005-78.5 meq L^{-1} with mean values of 6.03, 4.51, 11.49 and 0.32 meq L^{-1} respectively. The relative abundance of ions for most of the water samples are $Na^+ > Ca^{+2} > Mg^{+2} > K^+$. The concentration of anions viz., carbonate, bicarbonate, chloride and sulphate varied from 0-0.8, 0.8-12.2, 0.8-197

Table 1. Descriptive statistics for water quality parameters in Nandyal district

Parameter	Range	Mean
pH	6.5-8.4	7.26
EC(dSm^{-1})	0.4-22.3	2.07
CO_3^{2-}(me L^{-1})	0.0-0.8	0.01
HCO_3^-(me L^{-1})	0.8-12.2	6.22
Cl^-(me L^{-1})	0.8-197	9.87
SO_4^{2-}(me L^{-1})	0.02-8.84	1.73
Ca^{2+}(me L^{-1})	1.2-39.6	6.03
Mg^{2+}(me L^{-1})	0.0-56.0	4.51
Na^+(me L^{-1})	0.26-131	11.49
K^+(me L^{-1})	0.005-78.5	0.32
RSC(me L^{-1})	-91.2 to 7.6	-4.32
SAR	0.18-34.1	4.46
KR	0.07-10.9	1.35
SSP	6.99-88.45	43.61
PI	32.79-110	59.0

Table 2. Grouping of groundwater based on EC (dSm^{-1})

EC (dSm^{-1})	No. of samples	Per cent of samples
0-2	177	72.84
2-4	41	16.87
4-6	12	4.94
6-8	5	2.06
8-10	3	1.23
>10	5	2.06

and 0.02-8.84 meq L^{-1}. The relative abundance of ions for most of the water samples are HCO_3^-> Cl^-> SO_4^{-2}> CO_3^{-2}.The chloride and bicarbonate ions are dominant among all the anions then followed by sulphates and carbonates.

Spatial variability in SAR : The SAR of groundwater of Nandyal district ranged from 0.18Owk mandal - 34.1 (m mol $l^{-1})^{1/2}$ in Banaganapalle. The lowest SAR of 0.18 (m mol $l^{-1})^{1/2}$ in water samples was observed in . The highest SAR(>10) in groundwater was observed in parts of Gadivemula, Nandyal, Banaganapalle, Gospadu, Koilakuntla, Dornipadu, Uyyalawada. Based on SAR of groundwater most (91.77%) of the samples are <10 (m mol $l^{-1})^{1/2}$ in Nandyal district (Table 3, Fig. 4).

Spatial variability in RSC: The residual sodium carbonate (RSC) of groundwater in Nandyal district varied from –91.2 to 7.6 meq L^{-1} with a mean of -4.32 meq L^{-1} . The highest RSC of 7.6 meq L^{-1} in water samples was observed in parts of Kothapalle mandal. highest RSC (>2.5 me/L) in groundwater was observed with parts of Kothapalle mandal of Nandyal district (Fig. 5).The pH, EC and SAR of the irrigation water were significantly influenced by RSC. Based on RSC water can be categorized into three categories such as safe (<2.5 meq L^{-1}), moderately suitable (2.5-4.0 meq L^{-1}) and unsuitable (>4 meq L^{-1}). In the present study, it 235 samples were of safe category, 4 samples each were moderately suitable and unsuitable for irrigation purposes (Table 4). Naidu et al (2020) and Subbaiah et al (2022) also reported similar results with Nellore and Kadapa districts.

Grouping of Groundwater Quality for Irrigation

Minhas and Gupta classification: The groundwater of Nandyal district was classified into 7 classes for irrigation purpose (Minhas and Gupta, 1992) (Table 5). The irrigation water quality of groundwater classified as good (66.67%), marginally saline (19.75%), saline (3.29%), high SAR saline (7.41%), marginally alkali (1.65%), alkali (0.41%) and high SAR alkali (0.82%)**(Fig. 6).**

Wilcox classification: Based on soluble sodium per cent values (Wilcox 1955), the quality of groundwater was classified as excellent (11.11%), good (28.4%), permissible (44.44%), doubtful (14.40%) and unsuitable (1.46%). Overall majority of the samples are with less sodium hazard (Table 6).

Kelley's ratio: Kelley's ratio lies between 0.07-10.9 mg/L. Kelley's ratio value less than one is suitable for irrigation(108 samples) and more than one is unsuitable(135 samples).

Permeability index: The permeability index (of groundwater of Nandyal district varied from 32.79 to 110 (Table 7). Based on the permeability index classification given by Doneen (1964) 9.47 per cent samples of Nandyal district were suitable for irrigation, 90.53 per cent are marginal. Unsuitable quality was not reported. Permeability of soil was reduced due to the activity of high bicarbonate ions in irrigation water (Kumar and Kumar 2021)

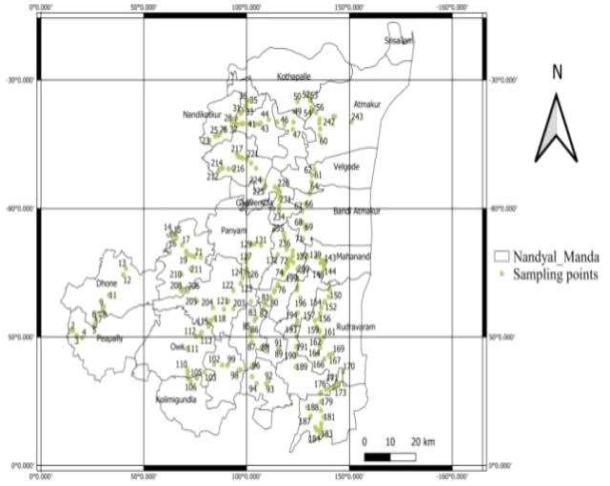

Fig 1 .Groundwater sampling points

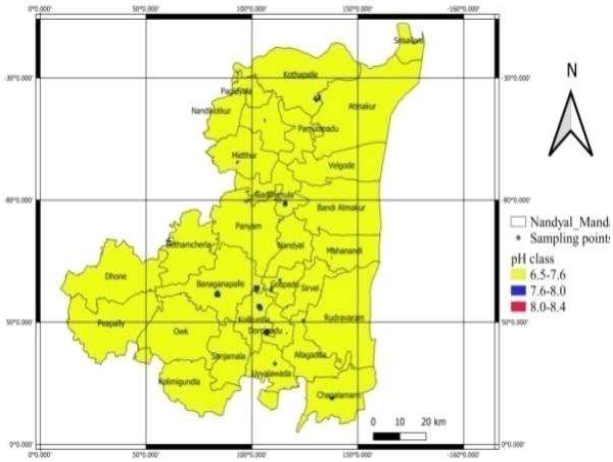

Fig 2. Spatial variability in pH of groundwater

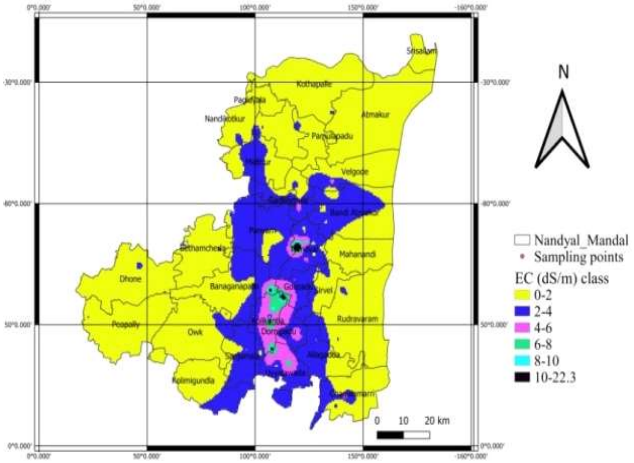

Fig 3. Spatial distribution of EC (dS/m) in groundwater

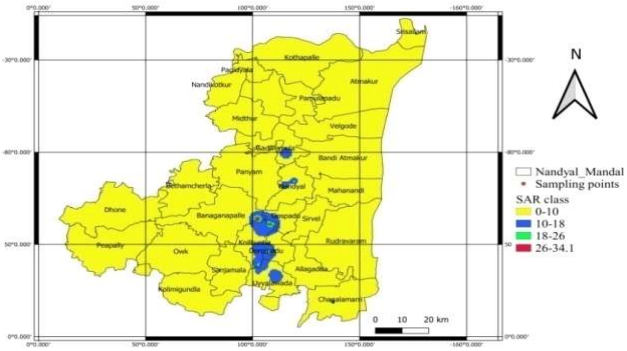

Fig 4. Spatial variability in SAR of groundwater

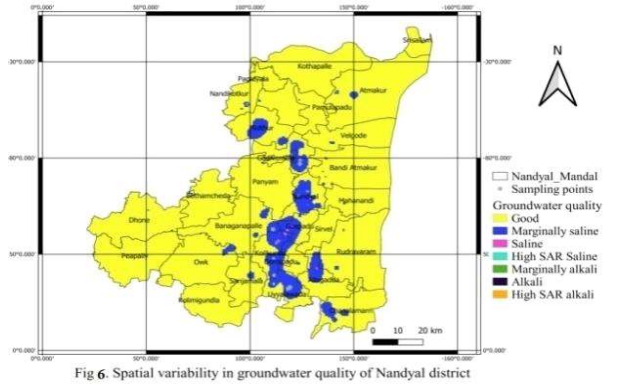

Fig 6. Spatial variability in groundwater quality of Nandyal district

Table 3. Grouping of groundwater based on SAR

SAR	No. of samples	Per cent of samples
<10	223	91.77
10-18	13	5.35
18-26	5	2.06
>26	2	0.82

Table 4. Grouping of groundwater based on RSC (mel^{-1})

RSC (mel^{-1})		No. of samples	Per cent of samples
Class	Value		
None	<2.5	235	96.71
Slight to moderate	2.5-4	4	1.65
Severe	>4	4	1.65

Effect geological conditions and soil type on ionic composition: The dominance of major ions was in the order of $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ for cations and $HCO_3^- > Cl^- > SO_4^{-2} > CO_3^-$ for anions (Table 8) Therefore, the chemical composition of the groundwater was characterized by Na^+- HCO_3^- type due

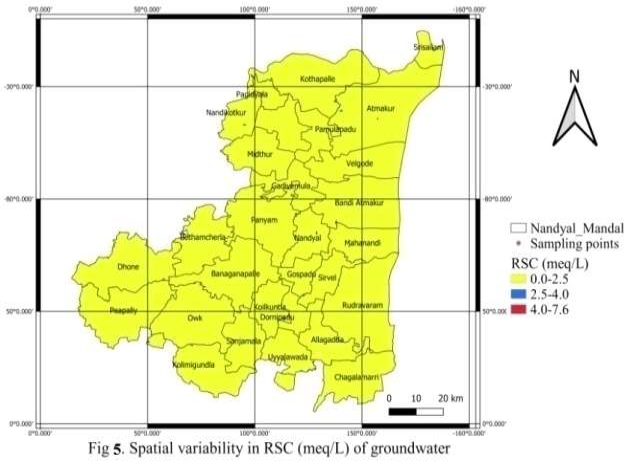

Fig 5. Spatial variability in RSC (meq/L) of groundwater

Table 6. Grouping of groundwater based on % Na values (Wilcox 1955)

Percent Na (After Wilcox 1955)	Classification	Total no. of samples	Percentage
<20	Excellent	27	11.11
20-40	Good	69	28.40
40-60	Permissible	108	44.44
60-80	Doubtful	35	14.40
>80	Unsuitable	4	1.65

Table 7. Grouping of groundwater based on permeability index (PI) for irrigation (Doneen 1964)

Classification of PI	Permeability	Suitability	Sample	
			Number	Per cent
I	>75	Suitable	23.00	9.47
II	25-75	Marginal	220.00	90.53
III	<25	Unsuitable	0.00	0.00

Table 5. Grouping of groundwater of Nandyal district for irrigation (Minhas and Gupta 1992)

Rating	Class	EC (dSm^{-1})	SAR	RSC ($me\ L^{-1}$)	Number of samples	Per cent Samples
A. Good	A	<2	<10	<2.5	162	66.67
B. Saline						
Marginally saline	B1	2-4	<10	<2.5	48	19.75
Saline	B2	>4	<10	<2.5	8	3.29
High SAR Saline	B3	>4	>10	<2.5	18	7.41
C. Alkali water						
Marginally alkali	C1	<4	<10	2.5-4.0	4	1.65
Alkali	C2	<4	<10	>4.0	1	0.41
High SAR alkali	C3	Variable	>10	>4.0	2	0.82

Table 8. Dominance of ions in groundwater of various mandals in Nandyala district

Name of the mandal	Type of rocks and minerals	Soil type	Groundwater type	GPS Co-ordinates
Nandyal	Shale, limestone	Loam	Na-Cl	15.476,78.435;15.473,78.489;15.458,78.475;15.487,78.489; 15.472,78.518;15.435,78.506;15.453,78.491;15.537,78.458; 15.524,78.459;15.521,78.46;15.492,78.467; 15.463,78.477; 15.462,78.482; 15.443,78.471;15.437,78.467;15.424,78.455;15.419,78.453
Nandikotkur	Lime stones	Red, black (loam)	Na-Cl	15.806,78.188;15.819,78.207;15.821,78.219;15.823,78.224; 15.841,78.243;15.856,78.269;15.869,78.276
Midtur	Limestone, shale	Red , black (loam)	Na-Ca -HCO_3-Cl	15.718,78.22;15.725,78.223;15.726,78.236;15.724,78.256; 15.725,78.271;15.767,78.287;15.760,78.291;15.758,78.301; 15.755,78.308;15.753,78.324;15.741,78.338;15.726,78.356; 15.692,78.376;15.675,78.387
Gadivemula	Shale	Red, black (loam)	Na-Cl-HCO_3	15.675,78.391;15.672,78.425;15.668,78.435;15.660,78.44; 15.656,78.442;15.652,78.441;15.638,78.441;15.618,78.44; 15.601,78.439
Pagidyala	Limes tone	Red	Ca-HCO_3	15.906,78.319;15.907,78.319;15.924,78.334;15.920,78.323
Jupadu bunglow	Shale, lime stone	Red	Na-Ca-Mg-Cl- HCO_3	15.871,78.285;15.885,78.30;15.889,78.304;15.854,78.289; 15.855,78.305;15.856,78.31;15.855,78.334;15.854,78.356; 15.854,78.368;15.857,78.374;15.867,78.402
Pamulapadu	Shale	Red	Na-Ca-Cl-HCO_3	15.860,78.434;15.851,78.459;15.839,78.49;15.860,78.492; 15.891,78.493
Kothapalle	Shale	Red	Na-Ca-HCO_3	15.919,78.506;15.939,78.541;15.924,78.552;15.922,78.552; 15.902,78.557;15.893,78.559
Atmakur	Quartzite	Red	Na-Ca-HCO_3	15.887,78.573;15.869,78.587;15.857,78.586;15.840,78.588; 15.821,78.587;15.876,78.637;15.876,78.642;15.860,78.701
Velugod	Quartzite	Red	Na-Ca-HCO_3	15.723,78.567;15.706,78.559;15.687,78.557;15.658,78.553
B.Atmakur	Quartzite	Red	Na-Cl	15.652,78.551;15.623,78.534;15.601,78.524;15.570,78.524; 15.557,78.534;15.551,78.534;15.522,78.526
Mahanandi	Quartzite	Red	Na-Ca-HCO_3	15.471,78.543;15.468,78.576;15.460,78.592;15.460,78.606; 15.456,78.609;15.453,78.605;15.451,78.603;15.443,78.603; 15.452,78.602;15.452,78.6;15.452,78.59;15.434,78.602
Rudravaram	Quartzite	Red	Na-Ca-HCO_3	15.374,78.623;15.354,78.619;15.340,78.606;15.338,78.603; 15.322,78.593;15.306,78.588;15.291,78.584,15.285,78.57; 15.267,78.575;15.258,78.584;15.252,78.588;15.237,78.602; 15.223,78.592;15.221,78.59;15.207,78.588;15.187,78.577; 15.174,78.604;15.185,78.62;15.186,78.622;15.188,78.634
Allagadda	Barites	Red, black (loam)	Ca-HCO_3	15.137,78.671;15.104,78.653;15.100,78.65;15.092,78.64; 15.090,78.638;15.088,78.619;15.086,78.609;15.077,78.591; 15.074,78.589;15.151,78.50;15.184,78.501;15.209,78.502; 15.240,78.503
Chagalamarri	Limestone, shale, quartzite	Red	Na-Ca -HCO_3-Cl	15.050,78.591;15.024,78.591;15.006,78.60;14.987,78.593; 14.973,78.591;14.959,78.589;14.968,78.576;14.976,78.57; 15.009,78.554;15.034,78.541
Sirivella	Limestone, shale, quartzite	Black (loam)	Na-Ca -HCO_3-Cl	15.275,78.504;15.285,78.506;15.307,78.508;15.351,78.517; 15.374,78.505;15.390,78.621
Gospadu	Limestone, shale, quartzite	Black (loam)	Na-Cl	15.390,78.436;15.386,78.434;15.373,78.424;15.367,78.421; 15.353,78.408;15.337,78.391;15.385,78.505;15.407,78.506
Koilakuntla	Limestone with shale	Black (loam)	Na-Cl	15.293,78.358;15.285,78.351;15.253,78.336;15.243,78.337; 15.224,78.34;15.208,78.376;15.155,78.343
Uyyalawada	Limestone with shale	Black (loam)	Na-Cl	15.110,78.402;15.102,78.393;15.103,78.359;15.123,78.342
Kolimigundla	Limestone with shale	Red	Ca-HCO_3	15.119,78.142;15.119,78.14;15.108,78.12;15.118,78.11
Owk	Shale, Limestone	Red	Ca-Na-HCO_3	15.121,78.11;15.135,78.109;15.143,78.108;15.204,78.106; 15.239,78.138;15.243,78.154;15.251,78.16;15.268,78.184; 15.273,78.188;15.136,78.17
Peapully	Shale	Red	Ca-HCO_3	15.258,77.687;15.255,77.693;15.242,77.707;15.235,77.726; 15.273,77.77;15.288,77.777;15.304,77.791
Dornipadu	Shale	Black (loam)	Na-Cl	15.204,78.439;15.205,78.441;15.205,78.438;15.320,78.384
Sanjamala	Shale	Black (loam)	Na-Cl	15.142,78.301;15.142,78.293;15.157,78.253;15.155,78.252; 15.156,78.234;15.158,78.205

Cont...

Table 8. Dominance of ions in groundwater of various mandals in Nandyala district

Name of the mandal	Type of rocks and minerals	Soil type	Groundwater type	GPS Co-ordinates
Banaganapalli	Sandstone, Lime stone	Red	Na-Ca-Cl-HCO_3	15.286,78.192;15.291,78.204;15.318,78.24;15.340,78.254; 15.342,78.256;15.372,78.275;15.393,78.301;15.409,78.308; 15.422,78.318;15.341,78.338;15.320,78.274;15.322,78.201; 15.341,78.143; 15.370,78.109
Bethamcherla	Limestone, dolomite	Red	Ca-Mg-HCO_3	15.540.78.05;15.533,78.057;15.524,78.068;15.504,78.088; 15.486,78.103;15.476,78.107;15.473,78.122;15.469,78.135; 15.468,78.157; 15.376,78.088;15.371,78.088;15.373,78.084;15.419,78.087; 15.434,78.119
Dhone	Limestone, Dolomite	Red	Ca-Mg-HCO_3	15.318,77.801;15.322,77.803;15.326,77.805;15.359,77.824; 15.418,77.875;15.436,77.885
Panyam	Quartzite, limestone, Shale	Red, black (loam)	Na-Ca-Cl-HCO_3	15.435,78.322;15.455,78.319;15.471,78.323;15.506,78.341; 15.507,78.352;15.503,78.374

Table 9. Correlation matrix among the chemical constituents of the groundwater

	pH	EC	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	Ca^{+2}	Mg^{+2}	Na^+	K^+	RSC	SAR	KR	PI	SSP
pH	1														
EC	0.127	1.000													
CO_3^{-2}	0.042	-0.034	1.000												
HCO_3^-	0.009	0.190	0.063	1.000											
Cl^-	0.070	0.952**	-0.028	0.122	1.000										
SO_4^{-2}	0.189	0.845**	-0.062	0.177	0.722**	1.000									
Ca^{+2}	-0.062	0.818**	-0.058	0.057	0.828**	0.719**	1.000								
Mg^{+2}	0.007	0.867**	0.016	0.195	0.922**	0.614**	0.773**	1.000							
Na^+	0.202	0.972**	-0.035	0.208	0.881**	0.857**	0.696**	0.762**	1.000						
K^+	-0.105	0.148	0.030	0.278	0.113	0.187	0.130	0.124	0.086	1.000					
RSC	0.030	-0.859**	0.043	0.086	-0.910**	-0.670**	-0.928**	-0.910**	-0.734**	-0.073	1.000				
SAR	0.329	0.811**	-0.036	0.304	0.667**	0.829**	0.456	0.505	0.909**	0.079	-0.447	1.000			
KR	0.431	0.479	-0.024	0.329	0.356	0.554	0.106	0.189	0.614**	0.031	-0.087	0.864**	1.000		
PI	0.398	0.238	-0.022	0.314	0.157	0.347	-0.089	-0.013	0.377	-0.092	0.122	0.614**	0.766**	1.00	
SSP	0.352	0.487	-0.012	0.365	0.387	0.635**	0.216	0.232	0.579	0.187	-0.158	0.774**	0.804**	0.863**	1.000

**Significant >0.6

to the presence of shale, limestone, quartzite and dolomite minerals and loam and red sandy loam soils. Significant positive correlation (Table 9) was observed between EC and Cl^-, SO_4^{-2}, Ca^{+2}, Mg^{+2}, Na^+, RSC and SAR.

CONCLUSIONS

The groundwater quality of Nandyal district varied from place to place due to different geological and soil type, drainage and climate of the district. The groundwater type is Na-HCO_3^- type. High EC and SAR of groundwater was observed in parts Gadivemula, Nandyal, Gospadu, Koilakuntla, Dornipadu, Uyyalawada mandals of Nandyal district and high RSC in parts of Kothapalle mandal of Nandyal district. Farmers were advised to take up suitable reclamation measures against RSC and SAR and conjunctive use with good quality groundwater is recommended for high EC water.

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Impact of Road Construction and Agriculture on Soil Aggregate Stability and Aggregate-Soil Organic Carbon: Ultisols of Derived Savannah

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Abstract: The escalating demands of urbanization and population growth in Southeastern Nigeria have subjected the region's soil to increasing pressures from both engineering works and agricultural practices. This study investigates the impact of road construction and agriculture on soil aggregate stability indices (ASI) and aggregate soil organic carbon (ASOC). Two locations, Nsukka and Neke Umo, and five land use types: grazing fallow, forest, road grading, and cultivated areas, were examined in Southeastern Nigeria. Employing the transect method, soil samples were collected at 0-15 cm depth to analyze ASI and ASOC. The findings revealed that tillage and engineering activities negatively impacted aggregation, while grazing and forests promoted soil aggregation. Clay flocculation index (0.4-0.87), aggregated silt plus clay (74-415 g kg^{-1}), water-dispersible clay (36-57 g kg^{-1}), were strongly determined by particle size distribution (PSD), while variations in mean weight diameter (0.7-1.69 mm), linked to land use and PSD was not consistent. Nevertheless,, ASOC was influenced solely by land use, with grazing land and forests displaying higher SOC storage, compared to road grading and cultivated lands. Intriguingly, cultivation was more damaging than road grading in C storage. These findings provide insights for site-specific approaches to enhance soil structure and carbon storage.

Keywords: Road construction, Agriculture, Dispersion indices, Aggregation, Aggregate-SOC

Land serves as a vital resource, offering diverse benefits ranging from food security to social amenities. However, the unbridled exploitation of this limited resource without proper management poses a threat to its sustainability for future use (Verburg et al 2033). In Nigeria, the forces of industrialization and urbanization have led to the creation of new access roads and the re-grading of existing roads without proper asphalt covering (Faiyetole and Adewumi 2024). The escalating population, in turn, exerts pressure on agriculture to meet the demands for food security (Tavershima et al 2022). Civil engineering and agriculture, while utilizing the same material (soil), diverge in their approaches to soil management, may not consider the concept of soil security, which addresses the soil's pivotal role in providing food and other ecosystem services, along with potential threats to sustainability (Evangelista et al 2023). The process of road construction involves the removal of topsoil and compaction, leading to the loss of crucial soil properties such as organic matter, structure, water-holding capacity, and desirable bulk density (Sezgin Hacisalihoğlu et al 2019). Conversely, unsustainable agricultural practices in Nigeria, including continuous cultivation, unrestricted grazing, forest fires, and lumbering, are linked to a decline in soil properties such as percent aggregate stability, mean weight diameter and soil organic carbon storage (Ahukaemere et al 2012, Njoku 2018, Osakwe et al 2021).

Aggregate stability serves as an indicator of organic matter content, biological activity, nutrient cycling, porosity, and soil infiltration. Various indices, such as mean weight diameter, flocculation, and dispersion, have been utilized to predict soil erosion (Nanganoa et al 2019, Nunes 2020). Soil organic carbon enhances nutrient release, improves soil structure, and contributes to the biological and physical health of the soil, promoting climate change mitigation (Thangavel et al 2019, Liu et al 2019).

The detrimental effects of road grading on soil properties, coupled with the unsustainable use of agricultural lands, highlight the need for a comprehensive assessment of the impact on aggregate stability and soil carbon storage. Understanding these changes is crucial in the context of climate change scenarios, with implications for infrastructural services, food security, and climate change mitigation. This study addresses this gap by evaluating the effects of agricultural land use and road construction on soil aggregate stability and aggregate-associated soil organic carbon in Nsukka and Neke-Uno, Southeastern Nigeria.

MATERIAL AND METHOD

This investigation was carried out in Nsukka (NS) and Neke Uno (NU) located in Enugu State, within the derived savannah of southeastern Nigeria. Positioned between N06°.37.901' and N06°.51.138' latitude and E007°.32.024' and E0070.25.520' longitude, the region experiences a tropical wet season from April to October and a dry season from November to March, with an average annual precipitation of 1600 - 1800 mm and an average temperature of 28°C.

Enugu State's soils, originating from sedimentary deposits, fall under the Ultisol order (Soil Survey Staff 2010). Nsukka's soils, part of the Nsukka formation (Ezeaku et al 2015), are classified as Typic Paleustult(Ukaegbu and Akamigbo 2021). The soil is characterized by deep red to brownish-red soil (Igwe 2001, Nwite and Obi 2008) as a result of $Fe_2O_3$and Al_2O_3 known as sesquixides which consists the major cementing agent (Igwe and Akamigbo1999). Two soil series:Nkpolugu and Nsukka series were identified within Nsukka study location (Ukaebu and Akamigbo 2021). Neke Uno on the other hand, rests on the Campano-Maestrichtian sediment of South-Eastern Nigeria, known as the Enugu Shale, featuring dark grey, fissile shale with occasional thin beds of Siderite and Mudstone (Okamkpa et al 2018) (Table 1).

The study was laid as 2 * 5 factorial experiment, denoting two locations (Nsukka (NS) and Neke Uno (NU)) and five land use types (Grazing, Forest, Road Grading, Fallow, and Cultivated), was replicated thrice in a randomized complete block design. The **respective Geo-positions and elevations at each location across the land use types were read with GPS (Table 1).** Transect sampling method was employed to collect soil samples at 0-15cm depth, replicated three times for each of the five land use types in both locations.

Air-dried composite samples were sieved into > 2 mm and < 2 mm fractions for analysis. The former was utilized for water-stable aggregates, macro-aggregate stability indices, and carbon associated with water-stable aggregates, while the latter was used for particle size distribution, micro-aggregate stability indices, and soil organic carbon in bulk soil. Physical analysis involved hydrometer-based particle size distribution determination (Kalra and Maynard 1991). Micro-aggregate stability indices, including Water dispersible clay, Aggregated Silt + Clay (ASC), Clay ratio and Clay Flocculation Index (CFI), were calculated from silt and clay measurements in calgon and water as follows:

ASC = [Total clay (g/kg) + Total silt (g/kg)] – [WDC (g/kg) + WDS (g/kg)]

CFI I = Total clay (g/kg) - WDC (g/kg)/ Total clay (g/kg)

CR= [Sand (g/kg) + silt (g/kg)/ clay (g/kg)

The distribution of water stable aggregates was estimated by the wet sieving technique (Kemper and Rosenau 1986). To separate the water stable aggregate, 25 gm samples of the > 2 mm air dried aggregates was put on top of a nest of two sieves measuring 0.25 mm, 0.053 mm and was pre-soaked for 10mins in water. The sieves and their content were oscillated vertically, once per second, in water 20 times using 4cm amplitude. The resistant aggregates on each sieve were oven dried at 60 ºC for 24 hr and weighed. The mass of < 53 micron WSA was obtained by difference between the initial sample weight and the sum of sample weight collected on the >2 mm, 0.25 mm and 53 micron sieve nest.Mean weight diameter (MWD) was calculated:

$$MWD = \sum_{i=1}^{n} Wi\,Xi$$

Where Wi is weight of aggregate in the ith aggregate size range as fraction of dry weight of sample and Xi is mean diameter of any particular size range of aggregates separated by sieving. Soil organic carbon in whole soil and

Table 1. Description of study locations and land use history

Loc	Tex	LU	Latitude	Longitude	Elev(m)	LU history
NS	SL	GRZ	N060.51.163'	E0070.25.520'	476.7	UNN Pasture land
	SL	GRD	N060.51.138'	E0070.25.698'	472.4	UNN Road Project
	LS	FAL	N060.51.609'	E0070.26.107'	472.8	NF 12 years
	LS	FST	N060.51.393'	E0070.26.337'	476.4	Secondary Forest
	LS	CLT	N060.51.417'	E0070.26.280'	477.6	Arable >15years
NU	SL	GRZ	N060.38.360'	E0070.32.078'	206	Cattle Free Range
	SL	GRD	N060.37.901'	E0070.32.024'	193.2	Road project
	L	FAL	N060.38.374'	E0070.32.078'	204.2	NF >15years
	CL	FDT	N060.39.908'	E0070.31.850'	208.4	Secondary forest:
	SL	CLT	N060.38.404'	E0070.31.802'	204.2	Arable, >15 years

Elev.- Elevation, Loc.- Location, LU-Land use, GRZ-Grazing, RGD,, Road Grading, FAL, Fallow, Forest, FRS, CLT, Cultivated, NF, Natural fallow,NS- Nsukka, NU- Neke Umo, UNN- University of Nigeria, Nsukka, SL- Sandy loam, LS- Loamy sand, L- loam, CL- Clay loam

water-stable aggregates was assessed using the Walkey and Black wet oxidation method as modified by Nelson and Sommer (1996).

Statistical analysis: Data analysis was performed using Minitab statistical software. Tukey tests at 5% probability level was used to separate significant differences in the means of the variables examined. Simple linear correlation analysis was conducted using SPSS to establish relationships between aggregate stability indices, aggregate soil organic carbon and soil properties. These methodologies aimed to explore the impact of agricultural land use and road construction on soil aggregate stability and associated organic carbon in Nsukka and Neke Uno, Southeastern Nigeria.

RESULTS AND DISCUSSION

Influence of land use on soil particle sizes and micro aggregate stability indices: CLT(691 g/kg) andRGD (684 g/kg)showed significantly higher sand content compared to other land use types, attributed to topsoil disturbance during tillage and the removal of topsoil during road construction respectively (Table 2). The forest (FRS) and fallow (FAL) land use exhibited the highest clay content. This is consistent with the result of Osakwe et al (2013). The observed increase in sand content is indicative of soil degradation and a decline in soil fertility.

Variations in particle sizes between study locations were significant, attributed to differences in parent materials. The interaction of location and land use on PSD was highly significant, giving rise to different textures within and between locations (Table 1). The differences in soil series within NS location affected PSD hence FRS from Nsukka series depicted lower clay content compared to GRZ and RGD in Nkpologu series in the same location. Kolo et al (2022) reported that variations in texture in a land use study was not linked to land use which underscores the complexity of response of soils to land use. This also highlights the need for soil management practices tailored to the specific characteristics of different soil environments. CLT land use exhibited the highest water-dispersible clay (WDC) and the lowest aggregated silt plus clay (ASC) (Table 2), suggesting that tillage destroyed aggregation and enhanced clay release (Li et al 2023).

The location effect indicated 55 and 20 % higher ASC, CFI and 90 % lower CR in NU respectively compared to NS. The comparison provided insight into differences that may exist in the susceptibility of soils to erosion in different soil environments. However, higher yield of WDC in NU

Table 2. Influence of land use on soil particle sizes and micro aggregate stability indices in study locations

Parameter		Sand	Clay	Silt	WDC	ASC	CR	CFI
L U	GRZ	656bc	146bc	195a	47b	197bc	5.88a	0.68a
	RGD	684a	143bc	172a	46b	175bc	6.17a	0.68a
+	FAL	639c	171ab	187a	43b	227b	6.99a	0.68a
	FRS	614c	200a	188a	45b	250a	6.62a	0.63a
	CLT	691a	126c	177a	54a	169c	7.34a	0.54b
LOC.								
	NU	515b	204a	282a	50a	280a	0.72a	4.58b
	NS	803a	111b	84b	44b	127b	0.57b	8.67a
LU LOC								
NS	GRZ	742C	139cd	119b	36.0c	180bc	0.74abc	6.18bc
	RGD	764bc	147cd	89bc	40.8bc	162bcd	0.71abcd	5.86C
	FAL	841a	84e	75bc	36.0c	108dc	0.56de	11a
	FRS	862A	84e	54c	50ab	74d	0.40f	11.08a
	CLT	820ab	99de	81bc	57.6a	109cd	0.41ef	9.11ab
NU	GRZ	569d	152c	272a	57.6a	214b	0.62cd	5.6cd
	RGD	635d	140cd	256a	50.4ab	187bc	0.63cd	6.5bc
	FAL	435e	258b	300a	50.4ab	346a	0.80ab	2.86de
	FRS	368e	310a	315a	40.8bc	426a	0.87a	2.15e
	CLT	569d	272a	152c	50.4ab	228b	0.67bcd	5.58cd

NU- Neke Uno, NS- Nsukka, LU- Land use, LOC-Location GRZ-Grazing, RGD- Road Grading, FAL- Fallow, Forest- FRS, CLT- Cultivated, WDC, -Water dispersible clay, ASC-Aggregated Silt + Clay, CFI,- Clay Flocculation Index, CR-Clay ratio

compared to NS , infers that WDC may be a function of total clay which aligned with the report of Osakwe et al (2014). The interaction of land use and location was highly significant, with FR and FAL in NU consistently showing higher CFI, ASC, and lower CR across all land use types. This underscores the role of intrinsic soil properties in controlling micro aggregate stability (Osakwe et al 2021a). Enhanced aggregation is crucial for soil pore connectivity, aeration, root penetration, and water infiltration. The decline in ASC may lead to soil dispersion, erosion, siltation, sedimentation, and pollution of water bodies (Igwe and Udegbuna 2008).

Influence of land use on aggregate size distribution (ASD) and mean weight diameter (MWD): The effect of land use on ASD revealed that GRZ land exhibited the highest percentage of WSA in the 4-2 mm fraction, with the order of GRZ > FAL > FRS = RGD > CLT. In the 2-0.25 mm fraction, GRZ, FAL, and FRS had similar percentages, while RGD and CLT showed lower values (Table 3). This suggests that tillage and engineering activities led to the destruction of macro aggregates (> 0.25 mm), while grazing, fallow, and forests promoted soil aggregation. Micro aggregates (0.25-0.053 mm) increased in RGD, indicating potential macro aggregate loss during road construction. Furthermore, the MWD was highest in GRZ compared to all land uses while RGD and CLT depicted the lowest MWD (Table 3). The higher the MWD, the more resistant the soil is to erosion. The implication is that RGD, and CLT will increase soil erodibility and consequently reduce the soils ability to sustain ecosystem functions..NU, consistently showing higher WSA in all aggregate sizes and MWD compared to NS, suggesting NU's higher resistance to external forces. The higher yield of WSA at micro aggregate level in NU may be attributed to more colloidal materials compared to NS (Table 2). The interaction of land use and location on ASD demonstrated that GRZ in NS had the highest 4-2 mm WSA, attributed to effective pasture management. FRS and RGD in NS exhibited the lowest WSA due to the coarse nature of FRS soil (Table 1) and topsoil removal during construction respectively. For the 2-0.25 mm fraction, GRZ in NU had the highest value, similar to other land use types, except for CLT and RGD in NS and NU, respectively, which showed the lowest aggregation. The results indicated that tillage and engineering activities negatively impacted soil aggregation, influenced by both land use and soil characteristics.

The lowest WSA in the 0.25-0.053 mm fraction occurred in GRZ of NS, suggesting higher stability hence lower yield at the lower aggregate sizes, while RGD in NU exhibited the

Table 3. Influence of land use on aggregate size distribution (ASD) and mean weight diameter (MWD) in study locations

AGS (mm)		4-2	2-0.25	0.25-0.053	<0.053	MWD
Parameter			% WSA			mm
L U	GRZ	41.55a	28.98a	8.347c	10.30ab	1.59a
	RGD	23.16c	21.00b	25.28a	12.46a	0.96d
+	FAL	26.74b	30.69a	13.80b	11.27ab	1.23b
	FRS	25.65bc	27.70a	14.05b	9.49ab	1.04c
	CLT	17.12d	23.60b	16.62b	6.85b	0.89d
LOC.						
	NU	29.29a	27.6a	21.61a	9.70a	1.20a
	NS	24.52b	25.19b	9.53b	9.37b	1.003b
LO*LU						
NS	GRZ	46.48a	25.40ab	3.65e	Wr4	1.69a
	RGD	15.30ef	26.96ab	11.49cd	17.77a	0.78e
	FAL	33.87cd	29.27ab	11.49cd	5.79b	1.36c
	FRS	12.40f	26.29ab	11.55cd	7.07b	0.68ef
	CLT	14.56cd	18.02c	9.95d	4.62b	0.65f
NU	GRZ	36.83bc	32.55a	13.0cd	9.01b	1.49b
	RGD	31.00d	15.04c	39.07a	7.14b	1.14d
	FAL	19.60e	32.13ab	16.11cd	16.76a	1.10d
	FRS	38.92b	29.11ab	16.55c	9.91b	1.41bc
	CLT	19.69e	29.18ab	23.30b	9.09b	1.13d

See table 1 and 2 for details

highest value, indicating lower aggregate resistance. For <0.053 mm aggregate size, RGD and FAL in NS and NU had the highest values, implying reduced stability due to road construction and unprotected fallow. The MWD results reflected macro aggregation, with GRZ in NS having the highest value and CLT and FRS in the same location recorded the lowest value. The result suggests that land use and PSD influenced macro-aggregation, however their inconsistencies prevented a conclusion, indicating additional factors' involvement. The findings are consistent with Njoku's 2018 report, showing lower mean weight diameter (MWD) in crop land compared to other land uses. However, our study reveals higher MWD in Grazing land than Forest, contrary to Njoku's findings. This difference may be attributed to effective pasture management and inherent soil properties in present study sites.

Influence of land use on aggregate soil organic carbon (ASOC) and soil organic carbon in bulk soil: Significant effects of land use on soil organic carbon (SOC) were observed in aggregates and bulk soil (Table 4). FRS and GRZ consistently had the highest SOC across aggregate sizes and bulk soil, except for 4-2 mm WSA in GRZ. Lowest SOC accumulation occurred in FAL, CLT, and RGD. Remarkably CLT depleted SOC in the largest aggregates (4-2 mm WSA) emphasizing the impact of tillage on SOC associated with large aggregates. The effect of location on ASOC was significant at the macro-aggregate level, with NS exhibiting higher SOC in 4-2 and 2-0.25 WSA compared to NU. However, no significant difference was observed at the microaggregate level, indicating a decline in location effects with decreasing aggregate size. Bulk soil SOC was 4% higher in NU than NS, emphasizing the variability in SOC storage between locations and aggregates. Understanding both storage potentials is crucial for monitoring ecosystem carbon budgets in different soil environments.

The interaction of land use and location on aggregate-associated soil organic carbon highlighted NS's highest SOC storage potential in GRZ and FRS, except for 4-2 mm WSA in GRZ. Continuous cultivation in NS depleted SOC in large aggregates, emphasizing the importance of external organic carbon inputs. RGD at NS showed the lowest capacity to store carbon at 2-0.25 mm and 0.25-0.053 mm sizes, aligning with findings on road construction impacts reported by Nosareti et al (2016). The interaction of land use on SOCb values reflected highest values in GRZ at NS and FRS at NU, supporting the positive influence of grazing and forest land

Table 4. Influence of land use on aggregate soil organic carbon (ASOC) and soil organic carbon in bulk soil in study locations

AGS (mm)		4-2	2-0.25	0.25-0.053	
Parameter			ASOC (g/kg)		SOCb (g/kg)
L U	GRZ	18.42b	25.1a	15.80b	14.13a
	RGD	8.2c	8.39b	8.04d	8.55b
+	FAL	8.9c	7.69b	9.1d	8.71b
	FRS	24.15a	26.52a	20.81a	13.40a
	CLT	3.91d	9.40b	12.98c	8.91b
LOC.					
	NU	10.41b	13.65b	13.11a	10.96a
	NS	14.72a	17.21a	13.50a	10.52b
LO*LU					
NS	GRZ	13.81cd	18.88b	12.08cde	11.00b
	RGD	4.99g	12.89c	14.32cd	7.18ef
	FAL	10.19ef	6.89de	10.70def	11.04b
	FRS	17.00c	21.93b	19.08ab	17.29a
	CLT	7.83fg	7.66de	9,36ef	8.11de
NU	GRZ	23.05bc	31.40a	19.5a	17.19a
	RGD	11.52de	3.86e	1.77g	9.14bc
	FAL	7.78fg	8.5cde	7.5f	6.38f
	FRS	31.3a	31.11a	22.54a	9.51cd
	CLT	0.00h	11.15cd	5.30ef	9.71bC

See table 1 and 2 for details

Table 5. Correlation of aggregate stability indices, aggregate soil organic carbon with with particle size distribution and SOC in bulk soil (SOCb)

Location	Parameter	Sand	Silt	CLAY	SOCb
NU	WDC	0.74ns	0.64s	0.77ns	0.63n
	CFI	-0.97**	0.95**	0.98**	0.81ns
	CR	0.99**	0.9**	-0.98**	0.85ns
	ASC	-0.91**	0.97*	0.98**	0.88*
	MWD	-0.19ns	0.21ns	0.18ns	0.62ns
	ASOC1	-0.7ns	0.74n	0.68ns	0.93*
	ASOC2	0.29ns	0.23n	0.3ns	0.69n
	ASOC3	-0.55ns	0.41ns	0.59ns	0.72ns
NS					
	WDC	0.46ns	0.5ns	-0.39	-0.23
	CFI	-0.99***	0.81ns	0.85	0.54
	CR	0.97**	0.82ns	0.99***	-0.68
	ASC	0.99**	0.94***	0.93***	0.69ns
	MWD	-0.47ns	0.69ns	0.26ns	0.51ns
	ASOC1	0.03ns	-0.1ns	0.02n	0.41n
	ASOC2	0.01ns	0.09ns	0.09ns	0.62ns
	ASOC3	0.25ns	-0.09ns	-.35ns	0.44ns

WDC-Water dispersible clay, ASC-Aggregated Silt + Clay, CFI,- Clay flocculation Index, CR- Clay ratio,MWD-Mean weight diameter, ASOC1, SOC in 4-2 mm WSA, ASOC2, SOC in 2- 0.25 mm WSA, ASOC3, SOC in 0.25-0.053 mm WSA

use on SOC. Road construction in NU recorded the lowest SOC storage, confirming that land use practices are crucial for SOC enhancement.

Correlation of aggregate stability indices, aggregate soil organic with particle size distribution and SOC in bulk soil: Correlation analysis revealed strong relationships between soil particle sizes and microaggregate stability indices (r = 0.99 - 0.86) at both locations indicating that particle size distribution controls microaggregate stability (Table 5). However, MWD, ASOC, and ASD were not related to particle size and SOC except significant positive relationship of SOCb with ASOC in large WSA (4- 2 mm), suggesting the involvement of other factors in aggregation and carbon dynamics. Osakwe et al (2014) in a land use study in south eastern Nigeria related variations in aggregate properties to total clay, diothionate citrate bicarbonate iron oxide and SOC.

CONCLUSION

The study investigated the impact of road construction and agriculture on soil aggregate stability and associated soil organic carbon in southeastern Nigeria. The result demonstrated that road construction and tillage negatively impacted soil aggregation and soil organic carbon both in aggregates and in bulk soil with implications for soil erosion susceptibility, while grazing and forests promoted soil stability and carbon storage. The result also suggested that micro aggregate stability was strongly influenced by particle size distribution an inherent property of the soil other than land use. This underscores the importance of discouraging blanket management strategies and optimize management practices that target the peculiarity of different soil environment. While land use and particle size distribution exerted control over macro-aggregation their inconsistencies prevented a conclusive determination, indicating the involvement of additional factors in the observed variations. However, the research highlighted the significance of land use in influencing aggregate-associated soil organic carbon, with implications for carbon storage, ecosystem carbon budgets and climate change mitigation. Overall, the findings demonstrated the need for sustainable land management practices to mitigate the adverse effects of road construction and tillage on soil structure and C storage in southeastern Nigeria.

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Avifaunal Diversity and Feeding Guild Structure in and Around Unkal Lake: A Semiarid Urban Wetland in Karnataka, India

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***Abstract*:** The study assessed species composition and distribution of birds through food choices and habitat resources found in wetland and terrestrial habitat in and around Unkal lake. Total of 196 species from 62 families were identified, representing around 35% of the species reported from Karnataka. Rare and coastal birds are sighted due to the region's unique habitat. The avifaunal diversity was H'=4.44 and D=0.979. Hierarchical cluster analysis of the feeding specialization based on families showed that 119 species (60%) had multiple feeding habits; 75 species (40%) being specifics. Insectivore guild with abundance of 37% was the most dominant group distributed in multiple habitats. Terrestrial habitat (26.2%) was the most dominant constituting multiple feeding guilds with greater species diversity & abundance. Correspondence analysis revealed the weakest relationship between arboreal habitat & scavengers, whereas the strongest association among arial habitat & insectivores. Waterbird diversity shows variation with water depth/rainfall changes, as most waterbird diversity depends on shallow water and mud/marsh habitats. This study provides data on avian diversity, concerning threats and feeding guilds, which gives insight about role/information of the habitat. The need for proper conservation and development of this vital ecosystem through long term monitoring is the need of the time.

***Keywords*:** Birds, Hubballi, Dharwad district, Feeding guild, Microhabitat

Wetlands are widely recognized as dynamic ecosystems with diverse attributes, including distinctive avifauna. It has been estimated that about 35% of global wetlands have been lost since 1970 (Darrah et al 2019). The world's freshwater wetland is rich in species composition and serves as a habitat for about 40% of bird species and 12% of all animal species. The microhabitats of a wetland provide rich and quality shelter and food for the avifauna populations throughout the year (Mitsch and Gosselink 2007, Zakaria et al 2009, Zeleke et al 2015). In urban areas wetlands help recharge groundwater aquifers, cleanse polluted waters and act as sponges to mitigate floods. ("Urban wetland/water bodies management guidelines" 2011). In the era of rapid urbanization, the growing urban population can benefit by implementing appropriate planning and management of wetland get ecosystem services that are of prior importance (Maitry et al 2023).

Total wetland area in India is estimated to be 15.98 Mha, which is around 4.86 percent of the total geographic area of the country (Chakraborty 2021). In Karnataka, inland wetlands dominate, which account for 93.44% of the total wetland area (Ramachandra and Ahalya 2009). Dharwad district (13507.14 km^2) has a total wetland of 36 with area extent of about 44.0 km^2 (Profile of Wetlands in Karnataka 2004). In India wetlands loss is due to urbanization, land use changes, and pollution (Bassi et al 2014). Wetland areas situated in arid and semi-arid places play an important role in supporting migratory bird species (Gardiner 2010). About 10% of the bird species globally rely entirely on wetlands, with about 20% utilizing them for foraging, resting, breeding, and overwintering (Rannestad et al 2015, Kačergytė et al 2021).

Avifauna has long been regarded as an important model system for studying overall biodiversity as they are found in varied climatic zones and habitat types (Junior et al 2016). The number of species and their relative abundance of birds depend upon wetland characteristics such as size, water level, quality of water, availability and distribution of food resources, and presence of suitable roosting and nursery sites (Wiens 1989). Heterogeneity in the habitat affect habitat resources, ultimately determining the species diversity and richness in a given area (Lorenzón et al 2016). Urban areas with fragmented and patchy habitats can still support a high level of biodiversity in their woodlands, scrublands and wetlands (Panda et al 2020) as plentiful untapped resources such as food, shelter, nesting sites, and breeding areas seem to draw birds to urbanized areas (Čanády and Mošanský 2017).

A guild is a fundamental concept in avian ecology and is created when a community of birds uses the same class of environmental resources (Balestrieri et al 2015). Avian feeding guild studies help to explain the complexities in the

structure of an ecosystem and enhance the knowledge about the habitats of that particular ecosystem (Rathod and Padate 2017). In urban areas, where several smaller habitats and feeding guilds are more significant, a rich diversity of birds can be seen (Leveau and Leveau 2016). India is known to have 1377 bird species of which around 81 are endemic to the country (Lepage 2023), constituting about 12% of the world's avifauna (Praveen and Jayapal 2022). Out of the bird species found in India, 310 species rely on wetlands (Kumar et al. 2005; Praveen et al. 2020; Praveen and Jayapal 2022) and 212 species are globally threatened. (Khan and Manakadan 2020). In Karnataka 535 bird species have been reported (Praveen et al 2016).

There are few studies regarding the diversity and ecology of avifauna in this region (Uttangi 1985, Chakravarthy 1993, Desai et al 1999, 2000, 2005, Desai and Kallur 2001, Ghorpadé 2015). However no detailed studies have been conducted to examine the species diversity in relation to feeding guilds of the birds in wetlands of urban area from this region. Hence, the objective of the present study is to describe the species diversity, threat concerns and study feeding guilds based on microhabitat types and ecological status of birds in and around Unkal lake, Hubballi, Karnataka, India.

MATERIAL AND METHODS

Study area: Unkal lake supply potable water to the Hubballi city, Dharwad district of North Karnataka (15.377278° N 75.1067° E with an elevation of 2063ft) (Fig. 1). The total area of the lake measures around 213 acres, 13 gunta. The maximum depth of the lake is about 20-25 feet. The primary source of water to the lake is rain and drainage from catchment areas. The average annual rainfall of the region is about 890mm. Crops such as corn, jowar, green gram, chilly, onion, brinjal, ladies' finger, cucumber, tomato, ground nut, chickpea, soybean, etc are cultivated in the region. The diversity of the avifauna is abundant in the lake and its surroundings due to the presence of diverse habitats such as the marshland, seasonal swamps & grassy scrubland buffering the main water body.

The lake bank with shallow open water and the marshy areas support a variety of aquatic and semi-aquatic vegetation that provides an adequate resource spectrum for the avifauna. Associated with these aquatic florae are a rich population of zooplankton, aquatic & terrestrial arthropods, including insects, molluscs & fishes, which constitute to be the primary resource for the macrofauna, especially the avifauna. The prominent terrestrial and aquatic vegetation thriving in the study area were described. PlantNet, iTree were used to identify the flora.

Bird survey: The methodologies used for bird counts were both point & line transect methods. A total of 10-line transects of 100mtr each and 10-points were covered (Rajashekara and Venkatesha 2017). The distance between each line transect & point was about 200mtrs. For documenting birds around the open water body, in the marshlands, swamps, semi-arid thorn scrub land habitat and farmland, 50mtr radius around each point and the perpendicular distance of 50mtrs from each line transect was observed by walking at a constant pace for both visual and auditory sightings. Total count was used for birds in open waters (Bibby et al 2000) and were counted at three scanning points (Fig. 1) selected based on pilot surveys. To count the large flocks, the flock size was broken into units of 20 individuals (Hodges 1993). The survey was conducted in the peak activity hours of the dawn between (0600-0900 h) and subsequently in the evening hours between (1700-1900 h). Avifauna was identified by sight and call, and individual counts were recorded. Equipment used for photography & observation was NIKON DSLR (D5200) with a 300mm Nikkor telephoto lens and Olympus Binocular 10x50. The individual encounters, habitats, and feeding specialization were noted for further analysis.

As a field guide for identification (Grimmett et al. 2014) and reference for details on distribution, residential status & occurrence status (Mc Kinnon and Philips 1993; Aarif et al. 2017; Grimmett et al. 2014) were utilized and IUCN (2022) was used for information on conservation status. The avifaunal data portrayed here are from 30 surveys between 2016 & 2021, conducted from January to April and between September to December. Observations were recorded to assemble & interpret data on birds' feeding guild based on available literature (Ali and Ripley 1987). The levels of disturbance in and around the site were also recorded for further interpretation.

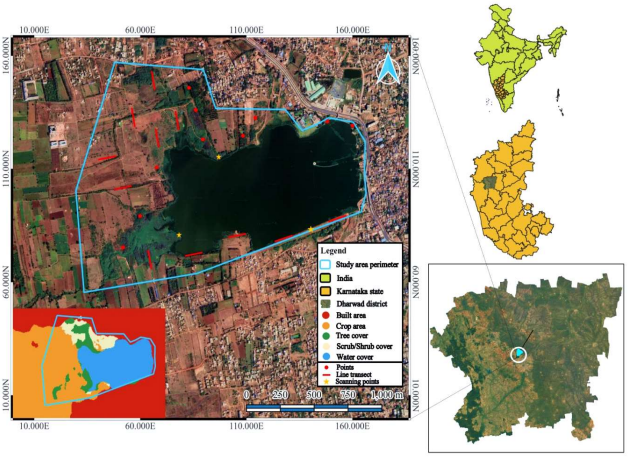

Fig. 1. Study area.-Unkal lake, Hubballi, Karnataka, India

Data analysis: The diversity indices, such as the Shannon-Wiener diversity index, Simpson diversity index, Correspondence analysis, cluster analysis, relative abundance, were calculated using PAST 4 statistical software and Microsoft Excel. The Shannon-Wiener Index is a way to measure the diversity of species in a community. The higher the index, the more diverse the species are in the habitat. If the index equals zero, only one species is present in the community. Simpson's Correspondence analysis is used to describe the relationships between two variables-habitat and feeding guild relationship.

The bird species were pooled into different feeding guilds based on their food preference and foraging areas (DeGraaf et al 1985, Gray et al 2007, Prajapati and Prajapati 2013, Ding et al 2019). The feeding specialization of birds was categorized as carnivores(C); insectivores(I); frugivores(F); granivores(G); nectivores(N); omnivores(O); scavenger(S); vegetable matter(V); piscivores (P), were clustered using the Jaccard similarity index through Unweighted Pair Group Method with Arithmetic mean (UPGMA) relating it to the family groups analysed on PAST4 software.

RESULTS & DISCUSSION

Bird species diversity, composition, and relative frequency: A total of 13,149 individuals from 196 species of birds belonging to 62 families were recorded from the field site (2016-2021). The Shannon and Simpson diversity index of the family-wise diversity was H'=3.947 and D=0.975. The Anatidae & Accipitridae with 13 species (RDi= 6.63%) was the dominant followed by Ardeidae, Scolopacidae and Muscicapidae with 8 species and Rallidae, Cuculidae and Passeridae with 7 species and Sylviidae with six species are the top five family groups (Table 1). Species composition in terrestrial and water habitats varies, comprising 128 species of terrestrial and 68 species of water birds respectively. The diversity indices indicate a variation in species diversity between the two habitats (Table 2).

There were almost twice the number of species in terrestrial habitats compared to water birds. Most importantly, diverse vegetation in the form of microhabitats around the water body gives an excellent platform for species variety as it provides a diverse niche for different bird species. Vegetation cover has been reported to strongly influence avifauna diversity (Radford et al 2005). Vegetation variety/micro-habitats are among the essential factors due to ample avian diversity. Contrary to the terrestrial habitat, the only reason that could extrapolate for considerably low diversity of water birds compared to terrestrial birds is the high-water level which floods the lake banks/ marshes. Lake water level fluctuates considerably from year to year creating temporary mud flats, which are crucial for wading birds. Some migratory visitors, such as Little Terns (*Sternulla albifrons*), visited the lake only in the particular year when the water level receded to expose muddy banks and puddles with bordering reed vegetation. Species abundance and richness rise with the increase in habitat variety and food availability. During the present study, occurrence of a rare species Great bittern (*Botaurus stellaris*) was first recorded from this region.

In terrestrial diversity Barn swallow (*Hirundo rustica*) tops the diversity index with H'=1.07 followed by Feral Rock Pigeon (*Columba livia*), Black Kite (*Milvus migrans*), Rose-ringed Parakeet (*Psittacula krameri*), Green Bee-eater (*Merops orientalis*), Red-rumped Swallow (*Cecropis daurica*), and Little Swift (*Apus affinis*) have the highest diversity index with values ranging from H'=1.04 – 1.05, where the species with the lowest diversity index are

Table 1. Relative diversity index (RDI) of all the families of avifauna

Families	Total no. of species	Rdi %
Anatidae Accipitridae	13	6.632
Ardeidae	12	6.122
Scolopacidae Muscicapidae	8	4.081
Rallidae Cuculidae Passeridae	7	3.571
Sylviidae	6	3.061
Phasianidae Laridae Columbidae	Hirundinidae Sturnidae	5	2.55
Ciconiidae Threskiornithidae Cisticolidae	Estrildidae Motacillidae	4	2.040
Phalacrocoracidae Charadriidae Hemiprocnidae Alcedinidae Laniidae	Pycnonotidae Phylloscopidae Timaliidae Emberzidae	3	1.530
Jacannidae Psittacidae Bucerotidae Dicruridae Corvidae	Alaudidae Dicaeidae Nectariniidae Ploceidae	2	1.020
Podicipedidae Anhingidae Falconidae Pandionidae Turnicidae Burhinidae Recurvirostridae Rostratulidae Glareolidae Pteroclidae Strigidae Caprimulgidae Upupidae	Coraciidae Meropidae Ramphastidae Picidae Aegithinidae Oriolidae Rhipiduridae Monarchidae Paridae Paradoxornithidae Zosteropidae Fringillidae	1	0.510

Eurasian Wryneck (*Jynx torquilla*), Western Crowned Warbler (*Phylloscopus occipitalis*), Verditer Flycatcher (*Eumyias thalassinus*), and Indian Courser (*Cursorius coromandelicus*). As the Barn swallow (*Hirundo rustica*) is a migrant, large flocks are seen along the length of telephone and electricity wire lines only during the winter. Among the water bird species, the Eurasian coot (*Fulica atra*) had the highest diversity index with H'=1.15, followed by Indian Spot-billed Duck (*Anas poecilorhyncha*), Garganey (*Spatula querquedula*), and Lesser Whistling-Duck (*Dendrocygna javanica*), with a diversity index that ranged from H'= 1.06-1.07. The relatively higher diversity index of Eurasian coot may be because of the large aggregations during winter months despite being a resident. The lowest diversity index amongst the water birds was of Ruddy-breasted Crake (*Porzana fusca*) with H'=1.0004, followed by Black-crowned Night-Heron (*Nycticorax nycticorax*), Baillon's Crake (*Porzana pusilla*), Great Bittern (*Botaurus stellaris*), Caspian Tern (*Hydroprogne caspia*), Brown Crake (*Amaurornis akool*), Black-tailed Godwit (*Limosa limosa*) with values that ranged from H'=1.0008-1.001.

Amongst the resident species, Shannon's diversity index was H'=3.774, and Simpson's diversity index showed D=0.936 (Table 3). Eurasian Coot (*Fulica atra*), Indian Spot-billed Duck (*Anas poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*), Cotton Pygmy-Goose (*Nettapus coromandelianus*), Purple Swamphen (*Porphyrio porphyrio*), and Little Cormorant (*Microcarbo niger*) had the highest diversity with a range of H'=1.04-1.14, where the occurrence of a high abundance of Eurasian coot and the Cotton pygmy goose was not constant throughout the year but only during the winter season. The residents with the lowest diversity index were Ruddy-breasted Crake (*Porzana fusca*) and Indian Courser (*Cursorius coromandelicus*) with H'=1.0004. They were found only once (June 2017) due to their rarity and being elusive/cryptic and also due to lack of stable habitat. Migrant avian diversity had Shannon's diversity index of H'=3.285 and Simpson's diversity index of D=0.934. Among the migrant species, Barn Swallow (*Hirundo rustica)*, Garganey (*Spatula querquedula*), and Northern Shoveler (*Spatula clypeata*) had the highest diversity that ranged from H'=1.09 to 1.12, and migrants with the lowest species diversity were Eurasian Wryneck (*Jynx torquilla*), Western Crowned Warbler (*Phylloscopus occipitalis*) and Verditer Flycatcher (*Eumyias thalassinus*) with H'=1.001.

The overall bird diversity of the study area was Simpson diversity index D=0.96 and Shannon diversity H'= 4.198. For further evaluation Eurasian coot was excluded as it occurred only between November 2017 and May 2018, as occurrence of such large gathering only once during more than five-year survey shows that it is not the regular part of the community structure in the ecosystem of the study area and that high abundance would negatively affect the diversity values of the study area. Hence the Shannon index value be H'=4.44 and Simpson index D= 0.979

True diversity is always measured in units of a number of species (Jost, 2006). Converting Shannon entropy (H'=4.44) to the effective number of species or true diversity is = 81.45 effective species and converting the Gini-Simpson index (D=0.979) gives 1/ (1-0.979) = 47.61 effective species. This indicates the degree of unevenness or dominance in the community. When there is a degree of dominance, the Shannon effective number of species will be less than the species richness (196), and the Gini-Simpson effective number of species will be less than the Shannon effective number of species. The greater the dominance in the

Table 2. True diversity of terrestrial & aquatic bird species

Parameter	Terrestrial birds	Effective no. of species	Water birds	Effective no. of species
Number of individuals	5321	-	7847	-
Species richness	128	-	68	-
Shannon's diversity index	4.143	62.99151281	3.121	22.669037
Simpson's diversity index	0.9756	40.98360656	0.8974	9.7465887

Table 3. True diversity of resident & migrant bird species

Parameter	Resident species	Effective no. of species for resident species diversity	Migrant species	Effective no. of species for migrant species diversity
Number of individuals	10006	-	3159	-
Species richness	125	-	70	-
Shannon's diversity index	3.774	43.5539	3.285	26.709
Simpson's diversity index	0.936	15.625	0.934	15.1515

community, the greater the differences between these three numbers (Jost 2006). Hence in the present community, the degree of abundance of some species is exponentially higher than many other species.

With the diversity of 47.61 effective species according to the Simpson index means that, the community has the same diversity as the community with around 47 equally common species.

Distribution status & frequency of occurrence: The residents constitute 125 species, among which 44 species (35.5%) were very common, 60 species (48.4%) common category, 17 species (13.7%) were uncommon, three species (2.4%) were rare. Among the 65 species of winter migrants, five species (7.7%) were very common, 20 species (30.8%) were common, 31 species (47.7%) were uncommon, eight species (12.3%) (Table 4) were rare in occurrence, and one species has been only reported once (1.5%). Under the summer migrant category, Pied/Jacobin cuckoo (*Clamator jacobinus*) was the only regular visitor. Four species of passage migrants are under the uncommon category, and two species occur rarely.

Conservation status & population trend: The data for the conservation status was referred from the IUCN Red list. From the total 196 species, 183 species belong to the Least concern category (93.8%), where the population trend of 78 species (42.4%) is stable, 48 species (26%) is decreasing, 29 species (15.8%) is increasing, and population trend of another 29 species (15.8%) is unknown. There are 8 species (4.1%) under the Near threatened category with decreasing population trend (Woolly-necked Stork (*Ciconia episcopus*), Painted Stork (*Mycteria leucocephala*), Black-headed Ibis (*Threskiornis melanocephalus*), Oriental Darter (*Anhinga melanogaster*), Laggar Falcon (*Falco jugger*), Pallid Harrier (*Circus macrourus*), Black-tailed Godwit (*Limosa limosa*), Malabar Pied-Hornbill (*Anthracoceros coronatus*) and four species (2.1%) under Vulnerable category with decreasing population trend (Indian Spotted Eagle (*Clanga hastata*), Lesser Adjutant (*Leptoptilos javanicus*), Common Pochard (*Aythya ferina*), River Tern (*Sterna aurantia*).

Habitat & Feeding guild structure: The field site habitat was divided further into 8 micro-habitats/niches. From the total diversity of 196 species richness, 54 species (27%) shared multiple niches from the site habitat. The data representation clearly showed that the Terrestrial habitat dominated the other habitats with species abundance (27.9%) due to the diverse vegetation cover. There are around 16 species of major terrestrial vegetation such as the invasive *Prosopis juliflora* (mesquite) being the dominant, covering around 30% of the study area, whereas Poaceae (three grass sps.) with 20% forming the second most dominant native plant species of the study area. Lantana sps., *Ricinus communis (castor oil plant)*, *Azadirachta indica (Neem)*, *Millettia pinnata* (Indian beech tree) and *Albizia saman* (Raintree), *Chromolaena odorata, Parthenium hysterophorus*, *Hyptis suaveolens*, *Leucaena leucocephala*, *Cocos nucifera*, *Acacia arabica and Mimosa pudica* has less than around 15% cover and remaining area is covered mainly by agricultural lands and some parts by horticultural lands. Receding to Terrestrial habitat (27.9%) is open water habitat, Ground, Open bank, Lake marsh, Arboreal, Arial and the lowest abundance was among the floating vegetation (5.3%) (Fig. 2).

The main reason for the difference in habitat preference by bird species could be due to different vegetation types and abundant food resources such as insects, fishes, frogs, lizards, mice, and vegetable matter. However, other factors include weather (rainfall), social interactions, and predators (Caldwell 1986, Butler and Vennesland 2000, Rivers 2000). In the study area, there is a good amount of marsh and swamp lands, which provide excellent habitats for frogs and toads to breed. Among the aquatic vegetation, Water

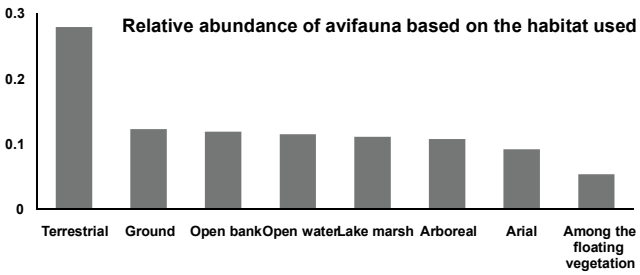

Fig. 2. Plot of the relative abundance of avifauna with different habitat preferences

Table 4. Avifaunal distribution status & frequency of occurrence

Occurrence frequency Distribution status	Very common	Common	Uncommon	Rare	Reported
Resident	44	60	17	4	0
Winter visitor	5	20	31	8	1
Summer visitor	0	1	0	0	0
Passage visitor	0	0	4	2	0

Table 5. Checklist of Avifauna based on the Families, Conservation Status & their population trend, residential and frequency status, feeding and habitat preferences

Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Phasianidae							
Indian Peafowl	*Pavo cristatus*	05	LC- S	R	O	VC	8/5
Gray Francolin	*Ortygornis pondicerianus*		LC- S	R	O	C	8
Painted Francolin	*Francolinus pictus*		LC-D	R	V/I	C	8
Common Quail	*Coturnix coturnix*		LC-D	WV	V/I	UC	8
Rock Bush-Quail	*Perdicula argoondah*		LC-D	R	V/I	C	8
Anatidae							
Lesser Whistling-Duck	*Dendrocygna javanica*	13	LC-D	R	V/O	C	2/1/3
Knob-billed Duck	*Sarkidiornis melanotos*		LC-D	PV	V/O	Ra	3
Ruddy Shelduck	*Tadorna ferruginea*		LC-U	WV	V/O	UC	2/1/4
Cotton Pygmy-Goose	*Nettapus coromandelianus*		LC- S	R	V/I	C	2/1
Garganey	*Spatula querquedula*		LC-D	WV	V/O	C	2/1
Northern Shoveler	*Spatula clypeata*		LC-D	WV	I/O	C	2/1
Gadwall	*Mareca strepera*		LC-I	WV	V/I	UC	2/1
Eurasian Wigeon	*Mareca penelope*		LC-D	WV	V/I	UC	2/1
Indian Spot-billed Duck	*Anas poecilorhyncha*		LC-D	R	V/O	VC	2/1/3
Northern Pintail	*Anas acuta*		LC-D	WV	G/O	UC	2/1
Green-winged Teal	*Anas crecca*		LC-I	WV	V/O	UC	2/1
Common Pochard	*Aythya ferina*		VU-D	WV	V/O	Ra	1
Podicipedidae							
Little Grebe	*Tachybaptus ruficollis*	01	LC-D	R	I/C	VC	1
Ciconiidae							
Asian Openbill	*Anastomus oscitans*	04	LC-U	WV	C/I	UC	4
Woolly-necked Stork	*Ciconia episcopus*		NT-D	R	C/I	C	8
Lesser Adjutant	*Leptoptilos javanicus*		VU-D	WV	P/C	UC	4/6
Painted Stork	*Mycteria leucocephala*		NT-D	R	P/C	C	4
Threskiornithidae							
Glossy Ibis	*Plegadis falcinellus*	04	LC-D	WV	I/C	UC	8/4
Black-headed Ibis	*Threskiornis melanocephalus*		NT-D	R	C/I	C	4
Red-naped Ibis	*Pseudibis papillosa*		LC-D	R	C/I	C	8/4
Eurasian Spoonbill	*Platalea leucorodia*		LC-U	R	C/I	UC	4
Ardeidae							
Great Bittern	*Botaurus stellaris*	12	LC-D	WV	C	Ra	3
Yellow Bittern	*Ixobrychus sinensis*		LC-U	R	C/I	UC	3
Cinnamon Bittern	*Ixobrychus cinnamomeus*		LC-S	R	C/I	UC	3
Gray Heron	*Ardea cinerea*		LC-U	R/WV	C/I	VC	3
Purple Heron	*Ardea purpurea*		LC-D	R	C/I	VC	3
Great Egret	*Ardea alba*		LC-U	R	C/I	C	4/3
Intermediate Egret	*Ardea intermedia*		LC-D	R	C/I	VC	4/3
Little Egret	*Egretta garzetta*		LC-I	R	I/C	C	8/4
Western Reef-Heron	*Egretta gularis*		LC-S	R	C/I	VC	8
Cattle Egret	*Bubulcus ibis*		LC-I	PV	I/C	UC	4/3

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Table 5. Checklist of Avifauna based on the Families, Conservation Status & their population trend, residential and frequency status, feeding and habitat preferences

Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Indian Pond-Heron	*Ardeola grayii*		LC-U	R	C/I	VC	4/3
Black-crowned Night-Heron	*Nycticorax nycticorax*		LC-D	R	C/I	C	4/3
Anhingidae							
Oriental Darter	*Anhinga melanogaster*	01	NT-D	WV	P/C	C	1
Little Cormorant	*Microcarbo niger*	03	LC-U	R	P	VC	1
Great Cormorant	*Phalacrocorax carbo*		LC-I	WV	P	UC	1
Indian Cormorant	*Phalacrocorax fuscicollis*		LC-U	WV	P	C	1
Falconidae							
Laggar Falcon	*Falco jugger*	01	NT-D	R	C	Ra	7/6
Pandionidae							
Osprey	*Pandion haliaetus*	01	LC-I	WV	P	C	6/1
Accipitridae							
Black-winged Kite	*Elanus caeruleus*	13	LC-S	R	C/I	C	6
Indian Spotted Eagle	*Clanga hastata*		VU-D	WV	C	UC	7/6
Booted Eagle	*Hieraaetus pennatus*		LC-S	WV	C	UC	7/6
White-eyed Buzzard	*Butastur teesa*		LC-S	R	C/I	UC	7/6/8
Eurasian Marsh-Harrier	*Circus aeruginosus*		LC-S	WV	C/I	VC	7/8
Pallid Harrier	*Circus macrourus*		NT-D	WV	C/I	Ra	7/8
Montagu's Harrier	*Circus pygargus*		LC-D	WV	C/I	Ra	7/8
Shikra	*Accipiter badius*		LC-D	R	C	VC	6
Eurasian Sparrowhawk	*Accipiter nisus*		LC-S	WV	C	UC	6
Black Kite	*Milvus migrans*		LC-S	R	C/S	VC	7/6/1
Black Kite (Black-eared)	*Milvus migrans lineatus/formosanus*		LC-S	R	C	VC	7/6/1
Brahminy Kite	*Haliastur indus*		LC-D	R	C/S	VC	7/6/1
White-bellied Sea-Eagle	*Haliaeetus leucogaster*		LC-D	PV	C	UC	6/7/1
Rallidae							
Eurasian Moorhen	*Gallinula chloropus*	07	LC-S	R	V/O	C	3/2
Eurasian Coot	*Fulica atra*		LC-I	R	V/O	VC	3/2/1
Purple Swamphen	*Porphyrio poliocephalus*		LC-U	R	V/O	VC	3
White-breasted Waterhen	*Amaurornis phoenicurus*		LC-U	R	I/O	VC	3
Ruddy-breasted Crake	*Zapornia fusca*		LC-D	R	I/O	UC	3
Brown Crake	*Zapornia akool*		LC-U	R	I/O	UC	3
Baillon's Crake	*Zapornia pusilla*		LC-U	WV	I/O	UC	3
Turnicidae							
Barred Buttonquail	*Turnix suscitator*	01	LC-I	R	V/I	C	8
Burhinidae							
Indian Thick-knee	*Burhinus indicus*	01	LC-D	R	I/O	C	8
Charadriidae							
Yellow-wattled Lapwing	*Vanellus malabaricus*	03	LC-S	R	I	C	8

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Table 5. Checklist of Avifauna based on the Families, Conservation Status & their population trend, residential and frequency status, feeding and habitat preferences

Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Red-wattled Lapwing	*Vanellus indicus*		LC-U	R	I	VC	8
Little Ringed Plover	*Charadrius dubius*		LC-S	R	I	UC	4
Recurvirostridae							
Black-winged Stilt	*Himantopus himantopus*	01	LC-I	R	C/I	VC	4/3
Rostratulidae							
Greater painted Snipe	*Rostratula benghalensis*	01	LC-D	R	O	C	3
Jacannidae							
Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	02	LC-D	R	I/O	C	2/3
Bronze-winged Jacana	*Metopidius indicus*		LC-U	R	V/O	VC	2/3
Scolopacidae							
Temminck's Stint	*Calidris temminckii*	09	LC-U	WV	I/O	UC	4/3
Little Stint	*Calidris minuta*		LC-I	WV	I/O	UC	4/3
Common Snipe	*Gallinago*		LC-D	WV	I/O	UC	4/3
Pin-tailed Snipe	*Gallinago stenura*		LC-U	WV	I/O	UC	4/3
Common Sandpiper	*Rostratula benghalensis*		LC-D	WV	I/O	C	4
Green Sandpiper	*Actitis hypoleucos*		LC-I	WV	I/O	UC	4
Marsh Sandpiper	*Tringa ochropus*		LC-D	WV	I/O	UC	4
Wood Sandpiper	*Tringa stagnatilis*		LC-S	WV	I/O	C	4
Black- tailed Godwit	*Limosa*		NT-D	WV	I/O	UC	3/4
Glareolidae							
Indian Courser	*Cursorius coromandelicus*	01	LC-S	R	I	Ra	8
Laridae							
Brown-headed Gull	*Chroicocephalus brunnicephalus*	05	LC-S	PV	P/O	UC	7/1
Little Tern	*Sternula albifrons*		LC-D	PV	P/I	UC	7/1/4
Caspian Tern	*Hydroprogne caspia*		LC-D	PV	P	Ra	7/1
Whiskered Tern	*Chlidonias hybrida*		LC-S	WV	I/P	C	7/1/4
River Tern	*Sterna aurantia*		VU-D	R	P/I	VC	7/1/4
Pteroclidae							
Chestnut-bellied Sandgrouse	*Pterocles exustus*	01	LC-S	R	G	UC	8
Columbidae							
Rock Pigeon (Feral Pigeon)	*Columba livia*	05	Not valid	R	G/F	VC	5
Eurasian Collared-Dove	*Streptopelia decaocto*		LC-I	R	G/V	C	5
Red Collared-Dove	*Streptopelia tranquebarica*		LC-D	R	G/V	UC	5
Spotted Dove	*Streptopelia chinensis*		LC-I	R	G/V	C	5
Laughing Dove	*Streptopelia senegalensis*		LC-S	R	G/I	VC	5
Psittacidae							
Rose-ringed Parakeet	*Psittacula krameri*	02	LC-I	R	F	VC	6
Plum-headed Parakeet	*Psittacula cyanocephala*		LC-D	R	F	C	6
Cuculidae							
Greater Coucal	*Centropus sinensis*	07	LC-S	R	C/O	C	5/8

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Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Blue-faced Malkoha	*Phaenicophaeus viridirostris*		LC-S	R	I/O	UC	5
Pied Cuckoo	*Clamator jacobinus*		LC-S	SV	I/O	C	5
Asian Koel	*Eudynamys scolopaceus*		LC-S	R	F/O	VC	6
Gray-bellied Cuckoo	*Cacomantis passerinus*		LC-S	R	I	C	5
Fork-tailed Drongo-Cuckoo	*Surniculus dicruroides*		LC-D	R	I/F	Rp	6
Common Hawk-Cuckoo	*Hierococcyx varius*		LC-S	R	I/F	UC	6
Strigidae							
Spotted Owlet	*Athene brama*	01	LC-S	R	I/C	C	5
Caprimulgidae							
Indian Nightjar	*Caprimulgus asiaticus*	01	LC-S	R	I	C	5
Hemiprocnidae							
Indian Swiftlet	*Aerodramus unicolor*	03	LC-D	R	I	UC	7
Little Swift	*Apus affinis*		LC-I	R	I	C	7
Asian Palm-Swift	*Cypsiurus balasiensis*		LC-S	R	I	UC	7
Upupidae							
Eurasian Hoopoe	*Upupa epops*	01	LC-D	R	I/C	C	8
Coraciidae							
Indian Roller	*Coracias benghalensis*	01	LC-I	R	C/I	UC	5
Alcedinidae							
Common Kingfisher	*Alcedo atthis*	03	LC-U	R	P/I	VC	3/1
White-throated Kingfisher	*Halcyon smyrnensis*		LC-U	R	I/C	VC	5
Pied Kingfisher	*Ceryle rudis*		LC-U	R	P/I	C	1/5
Meropidae							
Green Bee-eater	*Merops orientalis*	01	LC-I	R	I	VC	5
Bucerotidae							
Indian Gray Hornbill	*Ocyceros birostris*	02	LC-S	R	F/O	C	6
Malabar Pied-Hornbill	*Anthracoceros coronatus*		NT-D	R	F/O	C	5
Ramphastidae							
Coppersmith Barbet	*Psilopogon haemacephalus*	01	LC-D	R	F	C	6
Picidae							
Eurasian Wryneck	*Jynx torquilla*	01	LC-D	WV	I	Ra	5
Aegithinidae							
Common Iora	*Aegithina tiphia*	01	LC-U	R	I	VC	6
Laniidae							
Brown Shrike	*Lanius cristatus*	03	LC-D	WV	I/C	VC	5
Bay-backed Shrike	*Lanius vittatus*		LC-S	R	I	C	5
Long-tailed Shrike	*Lanius schach*		LC-U	R	I/C	VC	5
Dicruridae							
Black Drongo	*Dicrurus macrocercus*	02	LC-U	R	I	VC	5
Ashy Drongo	*Dicrurus leucophaeus*		LC-U	WV	I	C	5
Oriolidae							
Indian Golden Oriole	*Oriolus kundoo*	01	LC-U	R	F/O	C	6
Rhipiduridae							
Spot-breasted Fantail	*Rhipidura albogularis*	01	LC-S	R	I	C	5

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Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Monarchidae							
Indian Paradise-Flycatcher	*Terpsiphone paradisi*	01	LC-S	R	I	C	5
Corvidae							
House Crow	*Corvus splendens*	02	LC-S	R	O/S	VC	5
Large-billed Crow	*Corvus macrorhynchos*		LC-S	R	O/S	C	5
Paridae							
Cinereous Tit	*Parus cinereus*	01	LC-I	R	I/O	C	5
Hirundinidae							
Dusky Crag-Martin	*Ptyonoprogne concolor*	05	LC-I	R	I	C	7
Barn Swallow	*Hirundo rustica*		LC-D	WV	I	C	7
Wire-tailed Swallow	*Hirundo smithii*		LC-I	R	I	C	7
Red-rumped Swallow	*Cecropis daurica*		LC-S	R	I	VC	7
Streak-throated Swallow	*Petrochelidon fluvicola*		LC-I	R	I	C	7
Alaudidae							
Rufous-tailed Lark	*Ammomanes phoenicura*	02	LC-S	R	G/I	C	8
Ashy-crowned Sparrow-Lark	*Eremopterix griseus*		LC-S	R	G/I	VC	8
Pycnonotidae							
Red-vented Bulbul	*Pycnonotus cafer*	03	LC-I	R	F/O	VC	5
Red-whiskered Bulbul	*Pycnonotus jocosus*		LC-D	R	F/O	VC	5
White-browed Bulbul	*Pycnonotus luteolus*		LC-S	R	F/O	C	5
Cisticolidae							
Common Tailorbird	*Orthotomus sutorius*	04	LC-S	R	I/N	VC	5
Ashy Prinia	*Prinia socialis*		LC-S	R	I	VC	5
Plain Prinia	*Prinia inornata*		LC-S	R	I	C	5
Zitting Cisticola	*Cisticola juncidis*		LC-I	R	I	C	5
Sylviidae							
Booted Warbler	*Iduna caligata*	06	LC-I	WV	I	UC	5
Sykes's Warbler	*Iduna rama*		LC-S	WV	I	UC	5
Paddyfield Warbler	*Acrocephalus agricola*		LC-D	WV	I	C	5
Blyth's Reed Warbler	*Acrocephalus dumetorum*		LC-I	WV	I	VC	5
Clamorous Reed Warbler	*Acrocephalus stentoreus*		LC-S	WV	I/O	VC	5
Lesser Whitethroat	*Curruca*		LC-S	WV	I/O	C	5
Phylloscopidae							
Common Chiffchaff	*Phylloscopus collybita*	03	LC-I	WV	I/O	UC	5
Greenish Warbler	*Phylloscopus trochiloides*		LC-I	WV	I/O	C	6
Western Crowned Warbler	*Phylloscopus occipitalis*		LC-S	WV	I	UC	6
Paradoxornithidae							
Yellow-eyed Babbler	*Chrysomma sinense*	01	LC-S	R	I/O	C	5
Timaliidae							
Tawny-bellied Babbler	*Dumetia hyperythra*	03	LC-D	R	I	UC	5
Large Gray Babbler	*Argya malcolmi*		LC-S	R	I/O	VC	5
Yellow-billed Babbler	*Argya affinis*		LC-S	R	O	VC	5
Zosteropidae							
Indian White-eye	*Zosterops palpebrosus*	01	LC-D	R	O	C	5
Sturnidae							
Rosy Starling	*Pastor roseus*	05	LC-U	WV	O	C	5
Brahminy Starling	*Sturnia pagodarum*		LC-U	R	O	C	5
Chestnut-tailed Starling	*Sturnia malabarica*		LC-U	WV	O	C	5
Common Myna	*Acridotheres tristis*		LC-I	R	O	VC	5

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Common name	Scientific name	Total no. of species	IUCN status-population trend	Residential status	Feeding specialization	Frequency of occurrence	Habitat
Jungle Myna	*Acridotheres fuscus*		LC-D	R	O	VC	5
Muscicapidae							
Asian Brown Flycatcher	*Muscicapa dauurica*	08	LC-S	WV	I	C	5
Indian Robin	*Copsychus fulicatus*		LC-S	R	I	VC	5
Oriental Magpie-Robin	*Copsychus saularis*		LC-S	R	I/O	C	5
Tickell's Blue Flycatcher	*Cyornis tickelliae*		LC-S	R	I	C	5
Verditer Flycatcher	*Eumyias thalassinus*		LC-S	WV	I/O	Ra	5
Bluethroat	*Luscinia svecica*		LC-S	WV	I/O	UC	5
Siberian Stonechat	*Saxicola maurus*		LC-S	WV	I	C	5
Pied Bushchat	*Saxicola caprata*		LC-S	R	I	VC	5
Dicaeidae							
Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	02	LC-S	R	F/I/N	C	6
Thick-billed Flowerpecker	*Dicaeum agile*		LC-S	R	F/I/N	C	6
Nectariniidae							
Purple-rumped Sunbird	*Leptocoma zeylonica*	02	LC-S	R	N	C	6
Purple Sunbird	*Cinnyris asiaticus*		LC-S	R	N	C	6
Passeridae							
House Sparrow	*Passer domesticus*	07	LC-D	R	G/O	C	5
Yellow-throated Sparrow	*Gymnoris xanthocollis*		LC-S	R	G/O	UC	5
Gray Wagtail	*Motacilla cinerea*		LC-S	WV	I	C	4/8
Western Yellow Wagtail	*Motacilla flava*		LC-D	WV	I	C	8/4
Citrine Wagtail	*Motacilla citreola*		LC-I	WV	I	Ra	8/4
White-browed Wagtail	*Motacilla maderaspatensis*		LC-S	R	I	VC	8
White Wagtail	*Motacilla alba*		LC-S	WV	I	C	4/8
Ploceidae							
Streaked Weaver	*Ploceus manyar*	02	LC-S	R	G/O	Ra	5
Baya Weaver	*Ploceus philippinus*		LC-S	R	G/O	C	5
Estrildidae							
Indian Silverbill	*Euodice malabarica*	04	LC-S	R	G/O	C	5
Scaly-breasted Munia	*Lonchura punctulata*		LC-S	R	G/O	C	5
Tricolored Munia	*Lonchura malacca*		LC-S	R	G/O	UC	5
Red Avadavat	*Amandava*		LC-S	R	G/O	C	5
Motacillidae							
Paddyfield Pipit	*Anthus rufulus*	04	LC-S	R	I	C	8
Blyth's Pipit	*Anthus godlewskii*		LC-S	WV	I	Ra	8
Tawny Pipit	*Anthus campestris*		LC-S	WV	I	Ra	8
Olive-backed Pipit	*Anthus hodgsoni*		LC-S	WV	I	UC	5
Fringillidae							
Common Rosefinch	*Carpodacus erythrinus*	01	LC-D	WV	G/O	UC	5
Emberzidae							
Black-headed Bunting	*Emberiza melanocephala*	03	LC-U	WV	O	UC	5
Red-headed Bunting	*Emberiza bruniceps*		LC-S	WV	O	UC	5
Gray-necked Bunting	*Emberiza buchanani*		LC-S	WV	O	UC	5

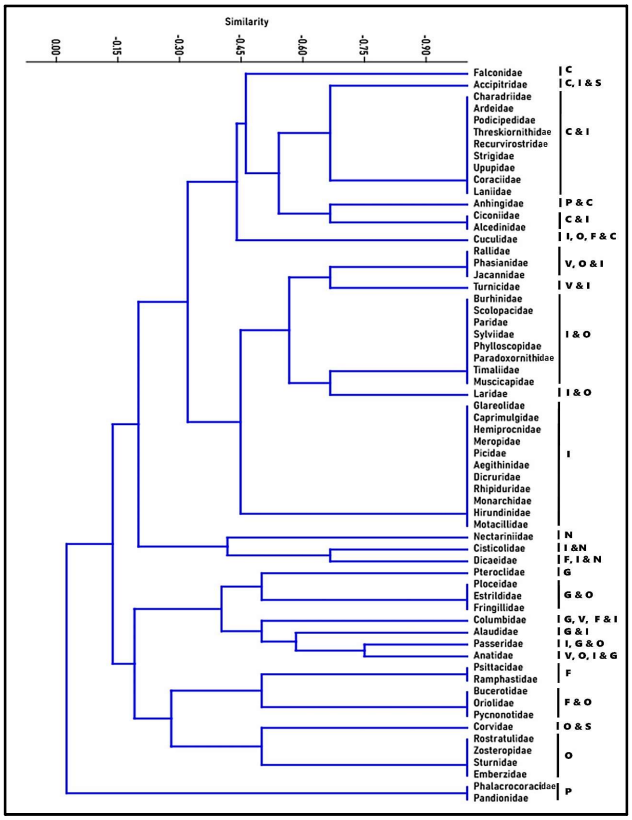
Threat Status: CR - Critically Endangered; EN - Endangered; VU - Vulnerable; NT - Near Threatened; LC - Least Concern.
Population trend: S – stable; D – decreasing; I – increasing; U – unknown.
Residential status: R = resident; WV = winter visitor; SV = summer visitor; PV = passage migrant
Feeding specialization: carnivores(C); insectivores(I); frugivores(F); granivores(G); nectivores(N); omnivores(O); scavenger(S); vegetable matter(V); piscivores (P).
Frequency of occurrence: V = very common; C = common; UC = uncommon; Ra = rare; Rp = reported.
Habitat: 1. Open water; 2. Among the floating vegetation; 3. Lake marsh; 4. Open bank; 5. Terrestrial; 6. Arboreal; 7. Arial; 8. Ground.

Hyacinth (*Pontederia crassipes*) being invasive covers approximately about 25%, followed by Typha spp., and *Ipomoea aquatica* that cover around 20%. The remaining aquatic vegetation cover includes, *Hydrilla verticillata* (water hymes), *Vallisneria*, *Cyperus* (nutsedges), *Spirodela spp.*, *Azolla*, *Aeschynomene aspera*, *Eriocaulon setaceum*, *Ottelia*, *Myriophyllum verticellatum*, *Nymphea spp.*, *Potomgeton spp.*, *Lemna spp. Wolffia globose* and *Spargonium spp*. With a variety of aquatic vegetation and terrestrial scrubs and bushes hosts a wide array of insect population of about more than 30 species of Lepidopterans and Odonata. The seasonal gathering of resident Common coots in hundreds and other migratory ducks during winter, particularly in this wetland, is due to the large water surface with both shallow and deeper areas and the presence of bordering aquatic vegetation and marshes. Other than the aquatic insects, crustaceans such as crabs, a variety of shrimps such as the bamboo shrimps, Amanos, grass and Ghost shrimps, various species of frogs and toads and abundant diversity of univalve molluscs provide a great source of nutrition to the waders and other water birds. More than 13 species of fish, from tiny Gambusia to Barbs, Tilapia to Carps, Minnows to *Ophiocephalus*, and Catfishes act as a food resource for a wide range of birds from divers to waders and Herons to Raptors. The trees, such as the *Acacia arebica* and *Cocos nucifera*, and even electric poles/lines provide good perch sites for resident and migratory Raptors. The reed beds in the lake banks are the only reason elusive species such as the Bitterns and Crake species thrive in the region.

The vegetation diversity and richness of Unkal wetland directly affect species diversity and richness of birds because it provides heterogeneous and suitable sites for foraging, nesting, and roosting (Karr and Roth 1971, Cody 1981, Soderstrom and Part 1999). There is some general agreement that marshes that undergo cyclic vegetation changes resulting from varying water levels show maximum avian use and production during the period when emergent macro-phytes and open water are present in equal proportions in an interspersed pattern (Weller and Spatcher 1965, Weller and Fredrickson 1974, Murkin et al 1997). Study by Chen et al (2016) suggest that the critical land use types for protecting endangered species of birds and good species diversity, in general, are medium grassland, tidal flat, and pond landscapes. Hence wetland restoration projects should keep these three-pointers as the basis of design.

The bird species were divided into eight feeding guilds. The first part of the study where family groups were classified into feeding specialization clusters (Fig. 3). Where the Insectivores covered 43 families, among which 14 were non-specifics, Carnivores covered 15 families with 14 non-specifics, Omnivores covered 26 families with only four specifics. In contrast, Piscivores covered three families with two specifics, the Frugivores covered seven families with two specifics, the Grainivores covered eight families with one specific, Nectivores covered three families with one specifics, Birds consuming Vegetative matter covered six families with all non-specifics and Scavengers covered only two families with all non-specifics. And among the 196 species, 119 (60%) had multiple feeding habits. Analysing the food preference revealed that Insectivores (39%) dominated other feeding guilds compared to Omnivores (22.8%), Carnivores (14%), Vegetable matter (6.9%), Granivores (5.7%), Frugivores (4.7%), Piscivores (3.8%), Nectivores (1.5%), Scavenger (0.6%).

Nudds and Bowlby (1984); Jose and Zacharias (2003) stated that the level of avifaunal diversity in the study area may be due to a wide spectrum of food niches. The different species of birds occupying a particular feeding guild and space have evolved specialized foraging strategies to



Feeding specialization: carnivores(C); insectivores(I); frugivores(F); granivores(G); nectivores(N); omnivores(O); scavenger(S); vegetable matter(V); piscivores (P)

Fig. 3. Hierarchical cluster analysis of feeding specialization based on families

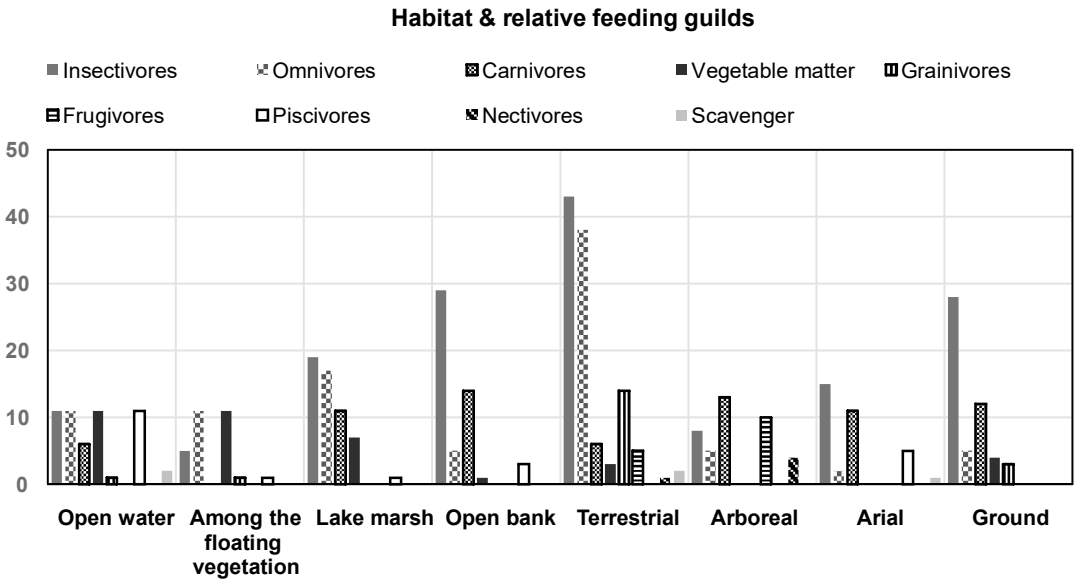


Fig. 4. Relation between avifaunal groups with various habitat preferences and feeding specialization

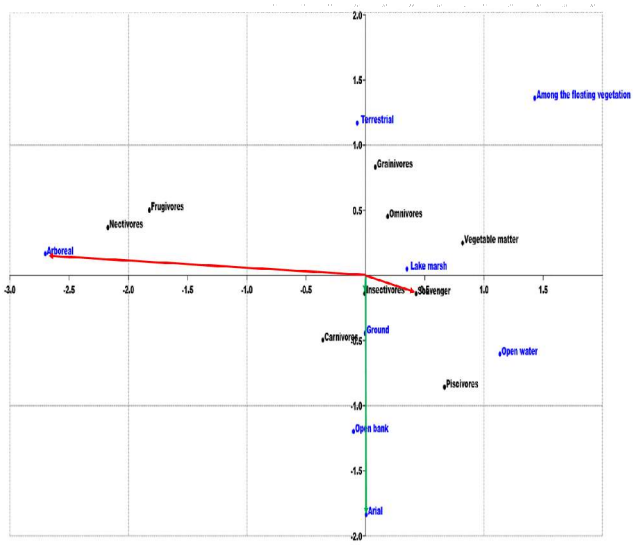


Fig. 5. The most positively related are arial habitat and insectivores and the most negatively related are arboreal habitat and scavengers

Image credits ©Harshavardhan Jamakhandi
Image 1: **A** – *Ixobrychus sinensis*; **B** – *Leptoptilos javanicus*; **C** - *Egretta gularis*; **D** - *Sternula albifrons*; **E** – *Chlidonias hybrida*; **F** – *Chroicocephalus brunnicephalus*; **G** – *Haliaeetus leucogaster*; **H** – *Botaurus stellaris*; **I** – *Cursorius coromandelicus*; **J** – *Accipiter nisus*; **K** – Aythya ferina; **L** – *Hydroprogne caspia*; **M** – *Mareca penelope*

Image 1. Few uncommon/rare and elusive Avifauna in & around Unkal lake

explore and obtain food resources efficiently and thus reduce competition among diverse species.

The occurrence of a significant number of insectivorous bird communities indicates that the area consists of rich insect diversity and similar observations have been by (Gregory et al 2004, Gajera et al 2012, Rajashekara and Venkatesha 2015, Sharma and Kichloo 2015). Hence they also plays a significant role as important bio-control agents of insect pest of agriculture, horticulture, and forest ecosystem (Mahabal 2005, Thakur et al 2010).

The composition of feeding guilds based on the presence in multiple habitats was examined to understand the importance of the habitats for different groups. The study showed that Insectivore with an abundance of (37%) was the most dominant group with most species occupying all habitat types. The least dominant guild was the Nectivores making their presence in just two habitat types (terrestrial, arboreal) (Fig. 4). Considering habitat in relation to feeding guild, terrestrial habitat was the most dominant in comprising most feeding guilds with greater species abundance (26.2%). The least abundance of the same was of floating aquatic vegetation (6.8%) (Fig. 4). Correspondence Analysis was

used to analyse the relationship of different microhabitats with feeding guild structure. The weakest relationship was between the Arboreal habitat & Scavengers, whereas the strongest relationship was among the Arial habitat & insectivores (Fig. 5).

CONCLUSION

The data and observations from the present study portrays that the wetland with habitat heterogenicity and proper wetland physical factors can sustain complex structure of feeding guilds and avifaunal diversity and also study shows how anthropological influence can induce less diversity in an area and more abundance of certain species. The region holds high diversity of migrant species and most of them are regular visitors and considerable number of species are placed under various threatened category of IUCN. Though the study area is located in the core urban environment, the microhabitat surrounding the wetland is capable of supporting the varied avian fauna including generalist coastal and rare species of birds. However, increased urban developmental activities are causing habitat alterations, which has affected the bird population causing irregularity in few of the sensitive bird species including migratory species. Regular monitoring and habitat maintenance with conscious lake development plans are essential to conserve the wetland and the avifaunal population in this area.

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Yield Benefit of Selected Rice Landraces under Drought Stress at Germination

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Abstract: In this era of continuous industrialization and deforestation, where climate change is inevitable, adequate cereal crop production to meet global hunger is extremely difficult. Drought is one of the most alarming constraints to rice production. The purpose of this study was to assess the drought tolerance ability of six rice landraces grown in the western lateritic area of West Bengal along with an already established drought-tolerant variety. Drought stress was induced on the seeds during germination using Poly-Ethylene-Glycol (PEG) at three different concentrations (5, 10, and 20%). Morphological and biochemical parameters like germination percentage, root length, root-shoot ratio, proline accumulation, survivability was estimated after 10 days of treatment. Under stress, land races accumulated more amount of proline indicating better tolerance. The stress induction at the germination stage reduced the yield of 3 landraces by 8-10% whereas production of the check variety was reduced by 20%.These landraces were collected from rural areas where farmers do not cultivate them commercially but maintain them each year traditionally. These landraces if involved in breeding programs can be modified to develop high-yielding, true-drought-tolerant, climate-resilient variety that can ultimately benefit the farmers in coming days.

Keywords: Rice landrace, Drought stress, Poly-ethylene-glycol, Proline content, Yield

Rice (*Oryza sativa* L.) is one of the most important staple foods in the world, specifically in South and Southeast Asia that alone contributes to more than 20% of the global dietary energy supply (Panda et al 2021, De et al 2022). After China, India ranks second in the world in rice production, and West Bengal is known as the "bowl of rice" because it has the most agricultural land dedicated to rice cultivation (Mishra and Sinha 2012). The western part of West Bengal, comprises of red lateritic plateau area, is no exception when it comes to rice cultivation and faces physiological drought condition due to the low water holding capacity of the soil. Not only that, due to climate change and other pollution related reasons, the erratic rainfall pattern also causes a massive decline in *kharif* rice production in the upland areas where farming is totally rainfall dependent. Around 60% rainfall occurs within the first 14 rainy days, so the rainfall during the germination and seedling growth (July-September) is not enough for the optimum yield of Kharif rice (Ministry of Agriculture and Farmers Welfare, GOI, 2011). Rahman and Zhang (2016) observed that no true drought tolerant variety has been identified till date that can withstand drought at varying degrees (mild to severe) and at any growth stage. So, there is an urgent need to develop climate-resilient, high-yielding, true-drought-tolerant variety. Landraces are the most unexploited section and can be used as the donor of drought tolerance capacity. They are the store-hub of various biotic and abiotic stress-tolerant factors. The main aim of this study was to assess the drought tolerance capacity of six landraces collected from Purulia, Bankura (Western part of West Bengal) and subject them to drought stress at different degrees at germination stage and study their physiological, biochemical and agro-morphological parameters to analyze their productivity and stress tolerance.

MATERIAL AND METHODS

Plant materials: Seven germplasms were collected for this study, of which six are landraces namely, Vutmuri, Langalmathi, Bhuri, Lohasal, Aswinsal, Tulsikamal and an already established drought tolerant variety, Sahabhagidhan; collected from various farmers of Purulia and Bankura districts in West Bengal (Fig. 1).

Stress induction at germination stage: PEG (Poly-ethylene-glycol) was used to mimic the drought condition. Stress effect was imposed at three levels including a control set (Table 1).

Physiological, biochemical, and agronomic parameters: Previous reports showed that germination percentage (GP), root length (RL), root-shoot ratio (R:S) had direct correlation with drought tolerance (Pandey and Shukla 2015). Similarly, over accumulation of an amino acid, proline provides

resistance against water scarcity (Mishra et al 2018). Decrease in total chlorophyll (Chl) content of a plant under stress is also reported (Pandey and Shukla 2015). These characters were estimated for the germplasms after 10 days of treatment at each stress level as well as for the control set. After treating them they were shifted to polyhouse in plastic pots and normal watering was done. Their survivability percentage (SP) were recorded after 7 days of normal watering. Yield has been considered as a definitive character to identify drought tolerant germplasm, so the treated plants were grown till harvesting and various agro-morphological characters like number of tillers, panicle length and seed yield/plant were recorded.

Statistical analysis: The treatments were designed based on a complete randomized design of two factors. One factor used the germplasms and the second factor was dry stress at different levels with three replications. Association within the characters and with drought stress was studied by using Pearson's correlation matrix. SPSS software, Ver. 18 was used for statistical analysis.

RESULTS AND DISCUSSION

Variability study: Synergistic effect of both stress and germplasms significantly varied for each of characters at 0.01% level of significance.

Germination percentage: Rate of germination reduced as drought severity increased. Germination percentage was 100% for all the germplasms in control. At mild stress the established variety, Sahabhagidhan and three landraces Vutmuri, Aswinsal, and Tulsikamal showed 100% GP. But at 10% and 20% PEG treatment GP of Sahabhagidhan reduced to 80% and 60% respectively. Under severe stress highest GP was observed in Tulsikamal (90%) followed by Vutmuri, Aswinsal. Lohasal (80%). Only 1 landrace Bhuri did not survive this condition and died with no germination. This result corroborated with Purbajanti et al (2019).

Root length: Root length decreased as stress increased. At 5% stress RL was highest in Vutmuri, a landrace followed by the established variety. In moderate and severe condition highest RL was observed in landraces like Vutmuri, Aswinsal and Tulsikamal. Similar observations were also observed earlier scientist (Panja et al 2017, Saha et al 2019, Nasrin et al 2020).

Root: shoot: This ratio increased as stress increased. Under severe stress the R:S ratio was highest in Vutmuri which indicated RL was 6.15 times higher than the SL. Increase in root: shoot ratio indicates that food reserves are mostly invested in elongation of root as compared to shoot by altering carbohydrate partitioning (Xu et al 2015).

Proline content: Over accumulation of this amino acid provides stress tolerance by maintaining turgor pressure and acts as an excellent osmolyte. Highest amount of proline accumulation was in Vutmuri in all stress condition. The established variety showed higher proline content under mild stress, but in moderate and severe stress other landraces like Tulsikamal and Aswinsal showed higher values. Similar findings are also supported by Dien et al (2019).

Total chlorophyll: Total chlorophyll decreased as stress increased for all the germplasms. Though the landraces had higher amount of chlorophyll as compared to the established variety under stress condition. Stability of chlorophyll has direct effect on grain yield (Nahakpam et al 2015).

Survivability percentage: After normal watering SP was highest in landraces as compared to the established varieties.

Table 1. Osmotic potential and severity of stress at different concentrations of PEG

PEG concentration	Osmotic potential (bar)	Severity of stress
0%	0	Control or no stress
5%	-0.49	Mild stress
10%	-1.48	Moderate stress
20%	-4.91	Severe stress

Table 2. Character with synergistic effect of germplasms and PEG concentration

Source	Dependent variable	F-value	Significance
Intercept (PEG and Germplasms)	Germination percentage	935.112	.000*
	Root length	547.632	.000*
	Root:Shoot	113.179	.000*
	Proline under stress	479.287	.000*
	Total Chl	1118.090	.000*
	Survivability percentage	1289.826	.000*
	No of tillers	1018.677	.000*
	Panicle length	561.634	.000*
	Seed yield/plant	1220.290	.000*

*significantly different at 0.01 % level (P < 0.001)

Fig. 1. Seven germplasms: 1-Vutmuri; 2- Langalmathi; 3- Bhuri; 4- Lohasal; 5- Aswinsal; 6- Tulsikamal; 7- Sahabhagidhan

Other agro-morphological characters: No of tillers, Panicle length and seed yield/plant decreased with stress. Under severe stress seed yield of Sahabhagidhan reduced by 20% whereas reduction in Tulsikamal, Aswinsal, Vutmuri was 8, 9, 10% respectively.

Correlation study: Pearson's Correlation study provides a complete knowledge on inter-relationship of characters. Negative significant correlation between PEG concentration and GP, RL, Total Chl, SP, no of tillers, PL, and seed yield/plant was found. Positive significant correlation was observed between PEG stress and R:S, Proline content. Association between seed yield and other characters under

Table 3. Agro-morphological and biochemical parameters for each germplasm under no stress or control condition

Germplasm	Germination (%)	RL	R:S	Proline (ug/ml)	Total Chl	Survivability (%)	No. of tillers	Panicle length (cm)	Seed yield/ plant (g)
Sahabhagidhan	100	6.3	1.30	101.57	4.3	100	10	22.4	22.59
Vutmuri	100	6.5	1.62	96.91	4.7	100	12	23.1	20.91
Langalmathi	100	6.9	1.16	88.88	5.4	100	12	28.2	22.44
Bhuri	100	7.4	1.33	80.50	5.5	95.99	12	29.1	18.82
Lohasal	100	6.5	1.31	88.56	4.5	98.89	12	25.5	18.02
Aswinsal	100	7.1	1.18	90.49	4.8	100	14	24.0	19.44
Tulsikamal	100	5.6	0.99	97.65	5.1	100	10	19.2	20.09

Table 4. Agro-morphological and biochemical parameters for each germplasm under mild stress condition (5% PEG mild stress)

Germplasm	Germination (%)	RL	R:S	Proline (ug/ml)	Total Chl	Survivability (%)	No. of tillers	Panicle length (cm)	Seed yield/ plant (g)
Sahabhagidhan	100	6.0	1.65	205.12	4.0	77.50	10	21.9	21.90
Vutmuri	100	6.1	2.10	211.23	4.0	90.50	9	24.5	19.98
Langalmathi	80	4.1	0.94	131.08	3.9	82.15	8	25.5	20.21
Bhuri	70	3.5	0.81	101.01	3.0	71.01	7	23.1	14.09
Lohasal	90	4.5	1.10	166.49	3.9	85.11	10	22.1	16.10
Aswinsal	100	5.9	1.81	172.84	4.0	90.00	12	22.1	18.99
Tulsikamal	100	5.1	1.51	197.25	4.4	90.50	10	19.2	19.85

Table 5. Agro-morphological and biochemical parameters for each germplasm under moderate stress condition (10% PEG moderate stress)

Germplasm	Germination (%)	RL	R:S	Proline (ug/ml)	Total Chl	Survivability (%)	No. of tillers	Panicle length (cm)	Seed yield/ plant (g)
Sahabhagidhan	80	2.9	2.00	216.87	3.2	85.13	8	18.3	18.22
Vutmuri	100	3.6	2.55	230.11	3.9	88.50	9	20.4	19.00
Langalmathi	50	2.4	1.29	179.98	3.1	75.25	6	15.5	17.09
Bhuri	50	0.5	0.6	129.10	2.1	45.25	4	21.8	11.12
Lohasal	90	3.3	2.10	172.67	2.8	65.81	8	22.1	14.71
Aswinsal	100	3.6	1.84	222.98	3.1	85.90	10	22.0	18.10
Tulsikamal	100	3.5	2.11	228.12	3.2	85.22	8	19.0	19.00

Table 6. Agro-morphological and biochemical parameters for each germplasm under severe stress condition (20% PEG severe stress)

Germplasm	Germination (%)	RL	R:S	Proline (ug/ml)	Total Chl	Survivability (%)	No. of tillers	Panicle length (cm)	Seed yield/ plant (g)
Sahabhagidhan	60	1.2	2.75	249.35	2.3	67.01	5	16.8	18.07
Vutmuri	80	1.5	6.15	288.50	2.8	77.50	9	21.6	18.81
Langalmathi	40	0.2	1.05	225.78	2.1	55.70	5	16.3	14.36
Bhuri	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Lohasal	80	0.9	3.43	200.90	2.1	45.35	6	19.3	14.05
Aswinsal	80	3.4	2.41	256.11	2.5	75.91	8	20.6	17.50
Tulsikamal	90	3.2	1.61	270.35	2.8	78.21	8	17.9	18.48

Table 7. Pearson's correlation matrix

Parameters	PEG	Germination (%)	RL	R:S	Proline	Total Chl	Survivabilty (%)	No. of tillers	Panicle length	Seed yield/plant
PEG	1									
Germination (%)	-.591**	1								
RL	-.892**	.790**	1							
R:S	.409*	.221	-.208	1						
Proline	.624**	.156	-.348	.673**	1					
TotalChl	-.870**	.817**	.914**	-.095	-.228	1				
Survivabilty (%)	-.704**	.884**	.838**	.089	.073	.917**	1			
No. of tillers	-.763**	.888**	.901**	.080	-.102	.901	.915**	1		
Panicle length	-.611**	.766**	.673**	.129	.010	.771	.758**	.764**	1	
Seed yield/plant	-.511**	-.840**	.684**	.260	.292	.804**	.925**	.796**	.732**	1

*significant at 5%, **significant at 1% level

stress is of paramount importance as yield is the definitive character for selection to the breeder in drought condition. Seed yield/plant showed a high positive significant correlation with RL, Total Chl, No of Tillers, PL. So direct selection for these characters will be beneficial for choosing under stress.

CONCLUSION

Landraces like Vutmuri, Tulsikamal and Aswinsal showed better performance for almost all the parameters under moderate and severe stress as compared to Sahabhagidhan, the established drought-tolerant variety. Though in mild stress Sahabhagidhan showed higher yield, but as water scarcity increased the landraces were found to have more grain production. These three landraces can be used as donor parents in different breeding programs for developing high-yielding, drought-tolerant, climate-resilient lines. These can also be studied further for presence of any major QTL (Quantitative trait loci) directly associated to drought tolerance.

AUTHORS CONTRIBUTION

ADe conducted experiments and collected the data from the field, worked out data curation and formal analysis, and wrote the manuscript. A Dey devised and designed the research, supervised the research, and reviewed the manuscript. AK Sinha provided the experimental materials. S Raha and D Kar provided facilities and edited the manuscript.

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Distribution of Himalayan Red Fox (*Vulpes vulpes*), A New Neighbor to Humans in Lahaul & Spiti, Himachal Pradesh

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***Abstract*:** The study aimed to assess the distribution of red fox using camera traps in Lahaul and Spiti, Himachal Pradesh. Generalized linear modelling was used to understand the influence of environmental factors governing the distribution of red fox. Total effort of 222 camera traps yielded 103 spatially independent records of Himalayan Red fox in Lahaul and Spiti. The top model insinuates that the distribution of Himalayan red fox is influenced by variables elevation and distance to village. The elevation (β= -0.0004) negatively influence the distribution of Himalayan red fox whereas distance to village (β = 0.003) indicated positive influence on the distribution of the species. Avoiding higher elevation areas and living in close vicinity with humans might be due to easy access to anthropogenic food/garbage sites without competing with other carnivores in the landscape. Playing a crucial role as a mesocarnivore, this species actively regulates prey populations, thereby contributing significantly to the maintenance of the food chain. Consequently, ensuring the stability of this species' population becomes imperative for maintaining the ecological balance.

***Keywords*:** Red fox, Distribution, Camera traps, GLM, Lahaul & Spiti

The habitat use studies provide a basic understanding of species' ecology and understand their natural history, abundance, and distribution (Engler et al 2017). Understanding how the species respond to the environmental factors and how those factors are governing the distribution of species is imperative for formulating effective conservation and management plans (Singh et al 2019). The Indian Himalayan region (IHR) is home to a diverse range of flora and fauna including mesocarnivores which are distributed in the wide variety of habitats (Chandra et al 2018). Some of these species are geographically restricted and some are having a widespread distribution such as red fox (*Vulpes vulpes)*. It is distributed throughout Europe, Asia and Northern Africa, North America and Australia. In Indian Himalayan region is occupying areas from Kashmir to Sikkim (Shawl et al 2008). Being a generalist species, it is found both in natural and human-dominated landscapes in large parts of the world (Gloor et al 2001, Bidlack et al 2006, IUCN 2022). It occupies highly contrasting habitats and its distribution and abundance is determined to a large extent by food availability (Barton and Zalewski 2007, Rosalino et al 2010, Gallant et al 2012, Carricondo-Sanchez et al 2016). They play an important role in maintaining the ecosystem integrity by balancing the prey base. It preys on a wide range of animal species and feed opportunistically on food resources such as berries and human garbage (Hartova-Nentvichova et al 2010, Rosalino et al 2010). The threats to this species are highly localized and includes hunting, habitat degradation and fragmentation. However, their general versatility and eclectic diet are likely to ensure their persistence despite changes in landscape and prey base and are listed as *Least concern* according to IUCN 2022. The conservation of red fox is crucial for the survival of any top predators, as changes in preferred prey abundance could alter the population of predators and vice-versa. Literature highlights that mesocarnivore species at intermediate trophic levels generally show high species richness and diverse resource and habitat use (Prugh et al 2009, Roemer et al 2009).

In recent years mesocarnivores have received much attention due to decline of top predators (Ritchie and Johnson 2009). Several studies have indicated that the relative abundances of apex and meso-predators are negatively correlated (Berger et al 2008, Pasanen-Mortensen et al 2013). Apex predators are always dominant over and can directly influence mesocarnivores (Roemer et al 2009, De Oliveira and Pereira 2014). The manner in which terrestrial ecosystems are regulated is controversial, but it is undeniable that predators Lregulate prey populations and vice-versa and as a result maintain the ecosystem integrity. Long-term absence of such species could cause trophic cascades as prey populations would likely increase, leading to depletion of other resources. Conservation and management planning demands exhaustive information on

various life history traits of species including habitat utilization pattern (Margules and Pressey 2000). Study on habitat ecology broadly pinpoints that what habitat is species preferring that may have missed by population level analysis (Habblewhite et al 2007, Schofield et al 2010). Generalized linear model is one of the powerful tool for understanding the habitat use, risk assessment and distribution of the species. In IHR few studies are available on red fox which are limited to protected areas (Ghoshal et al 2016, Reshamwala et al 2018). The Himalayan region is under tremendous pressure because of infrastructural development, climate change and other anthropogenic activities (Western et al 2009, Qasim et al 2013). These events lead to rapid habitat loss, fragmentation, and population decline of various species. Therefore study aimed to identify the factors governing the distribution of red fox using camera traps in Lahaul and Spiti, Himachal Pradesh.

MATERIAL AND METHODS

Study area: The Trans-Himalayan district of Lahaul and Spiti (L&S) extends from 31°44'57" to 32°59'57"N latitudes, 76°46'29" to 78°41'34"E longitudes between the Pir Panjal Mountain chains of the Greater Himalaya and Trans Himalaya with a total area of 13,841 km^2 possesses forest cover of about 1.11% with varying elevation from 2327 to 6441 m (Fig. 1). The Lahaul and Spiti district hold 25% of the total cold dessert of India and is divided into Lahaul and Spiti. The Spiti region presents typical arid or xeric conditions, whereas the Lahaul valley possesses mix of great Himalayan and Trans-Himalayan condition. The Spiti region is bestowed with three protected areas, Pin Valley National Park, Kibber Wildlife Sanctuary, and Chandratal Wildlife Sanctuar, whereas the Lahaul region does not have any protected area. The land cover is mainly represented by subalpine vegetation, rolling grassland meadows, agricultural land and snow-covered permafrost area. Owing to harsh climatic conditions, low rainfall, and short growing season, the slopes of the Trans-Himalayan mountains of the landscape support low vegetation cover (<20%), and are known to harbour a unique assemblage of wild flora and fauna (Joshi et al 2006). Lahaul and Spiti only have two seasons, i.e. short-lived summers, and another is prolonged severe winter. The Lahaul valley has the sparse distribution of vegetation with dominant tree species like *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow*, *Betula utilis* and *Juniperus polycarpos* mostly at the left side of the downstream of Chandrabhaga river. The local communities largely depend on high yielding cash crops, exotic vegetables, and various fruits. Both the regions of Lahaul and Spiti provides suitable habitat for the various species such as Himalayan brown bear, Kashmir Musk deer, Siberian Ibex, Snow Leopard, Blue sheep, Himalayan red fox, Himalayan Wolf.

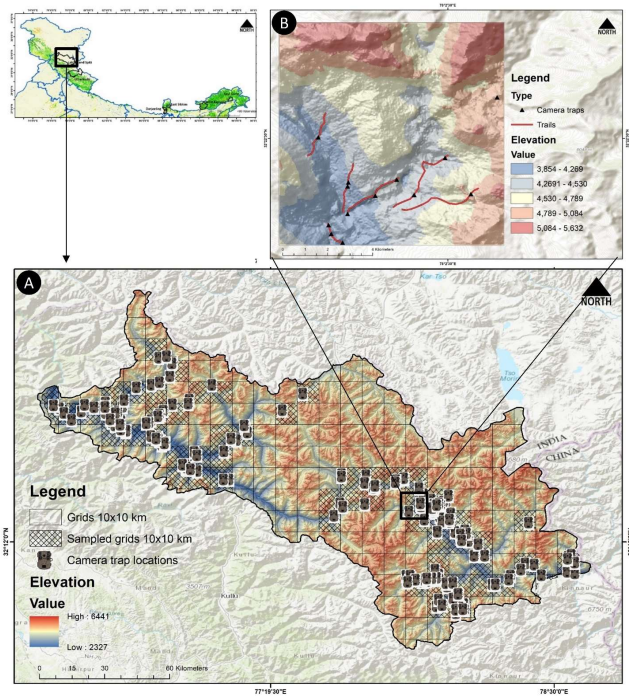

Fig. 1. Camera trap locations of red fox in Lahaul and Spiti, Himachal Pradesh

Methods: The study landscape was divided into 10 km X 10 km grids to maximize our sampling effort so that all logistically accessible grids could be covered (Sharief et al 2020). Field surveys were conducted from August 2018 to December 2020 in all the possible areas. A total of 222 camera traps were deployed covering different elevation gradients of the study landscape. The camera traps were placed at about 2.5 feet height from the ground on animal trails and paths and mostly kept 2-3 m apart from the trailsaend used ultra-compact SPYPOINT FORCE-11D trail cameras (SPYPOINT, GG Telecom, Canada, QC) during the study.

Covariates

A total of 20 variables were extracted either from the field or using the ArcGIS v. 10.9 software (ESRI, Redlands, CA). These covariates were classified into the following categories (topographic, habitat and anthropogenic variables). The topographic variables (elevation, slope and aspect) were generated using 30 m resolution SRTM (Shuttle Radar Topography Mission) image downloaded from Earth Explorer (https://earthexplorer.usgs.gov/). Land use landcover variables were extracted from MODIS (Moderate Resolution Imaging Spectroradiometer) Land Cover Type Product (MCD12Q1) version 6 with a 500-meter resolution to generate seventeen different land cover classes

https://earthexplorer.usgs.gov/. Landscape classified into 11 different land use land cover classes which were used for further analysis. The global human footprint dataset was downloaded from the Socioeconomic Data and Applications Centre SEDAC, NASA (https://sedac.ciesin.columbia.edu). Linear features (road and water) were downloaded from DivaGis (www.diva.gis.org). All the variables were resampled with 30 arcsec ~ 1 km spatial resolution using the spatial-analyst tool in ArcGIS 10.9. Pearson correlation test was performed to identify and remove variables exhibiting significant collinearity. Variables with Pearson coefficient greater than 0.8 (rs>0.8) were dropped from further analysis (Warren et al 2010). Finally, 12 environmental variables which assumed might have ecological effect on the distribution of the species were retained for further analysis (Table 1).

Data analysis: Camera traps images were carefully visualized to identify the species and a capture of an animal was considered independent if the consecutive capture was at an interval of 60 minutes (Bowkett et al 2007, Marinho et al 2017). Variables which were pertinent to the ecology of the species were explicitly used for understanding the ecology of the species. Generalized linear models (GLM) were implemented in 'glmer' function of package “nlme4” in R Studio with Binomial distribution using log link function (Teixeira-Santos et al 2020). Presence/absence of the species was used as a response variable and the effect of each or a combination of the different variables on the species habitat use was predicted (Ward-Paige et al 2015). Total of 20 models were run in different combinations. To infer the results, from a set of different competing models, the best model was selected based on the Akaike's information criterion (Burnham and Anderson 2002).

Table 1. Variables selected after Pearson corelation (rs>0.8) on distribution of red fox in Lahaul and Spiti

Variable	Code	Data	Source
LULC/Land use land cover type			
Western mixed coniferous forest	WMCF	MODIS MCD12Q1 16	USGS
Moist Deodar forest	MDF		
Dry alpine scrub	DAS		
Alpine grassland	AG		
Agricultural & horticultural land	AH		
Distance to village	DV	Calculated using log Euclidean distance (ArcGISx)	LULC map
Distance to water	DW		
Distance to road	DR		
Topographic variables			
Aspect	ASP	SRTM	USGS
Slope	SLP		
Digital elevation model	DEM		
Anthropogenic variables			
Human footprint	HFP	SEDAC, NASA	

RESULTS AND DISCUSSION

Total effort of 222 camera traps yielded 103 spatially independent records of Himalayan Red fox in Lahaul and Spiti. Out of 20 models, only top two models are shown (Table 2) which explains the influence of environmental variables on distribution of Himalayan red fox. The top model based on the lowest AIC showed that the habitat use of Himalayan red fox was influenced by variables elevation and distance to village. The model assumed that habitat use of red fox varied as a function of elevation and distance to village. The results indicate that elevation (β= -0.0004) is negatively influencing the distribution of Himalayan red fox and distance to village (β = 0.003) is positively influencing Himalayan red fox in the Lahaul and Spiti (Table 2). The generalized linear modelling was performed for Himalayan Red fox to understand the association with the habitat predictors in Lahaul and Spiti. The Red fox is one of the most widely distributed species in Lahaul and Spiti district, possibly near human settlements (Ghoshal et al 2015). The findings suggest that this species avoids high elevation areas and prefers to live near human settlements which might be due to less availability of food resources at high elevation areas and to avoid top predators such as snow leopard and wolf in the landscape. Hussain et al (2018) also suggested the ability of red foxes to exploit humans as sources of food appears to be a behavioral adaptation that helps them

Table 2. Top two models with beta estimates to understand the habitat association of red fox in Lahaul and Spiti District, Himachal Pradesh

Models	Variable	Estimate with SE	Z value	Pr(>|z|)	K	AIC	ΔAIC
(ELE+DV)	Elevation	-0.04± 0.0001	-2.62	0.008**	2	252	0
	Aspect	0.003± 0.001	2.35	0.018*			
ELE + ASP+ DAS)	ELE	-0.001±0.0002	-1.83	0.007*	3	254.47	0.47
	ASP	0.007±0.001	2.01	0.0006			
	DAS	0.002±0.0005	-3.62	0.00002			

ELE- elevation, DV -Distance to village, ASP- aspect, DAS- dry alpine scrub

to survive in the arid Trans Himalayan landscape. During survey period frequently observed red fox near human settlements which may be due to food availability from garbage sites, prey species available at lower elevations and to avoid resource competition. Cagnacci et al (2004) also observed that species avoid higher elevation during the winter season due to availability of prey species at the lower elevation. Increased food availability at garbage sites and absence of large carnivores increased the population of red fox in Scandinavia (Selas and Vik 2006). The rapid increase in tourism has led to a drastic increase in the number of restaurants and hotels in the trans Himalayan landscape of Lahaul and Spiti that have considerably contributed to garbage generation (USL 2011). Ghoshal et al (2015) suggested the positive association of red fox occurrence with the garbage sites which is a source of food for red fox. Increased food availability at garbage sites and absence of large carnivores increased the population of red fox in Scandinavia (Selas and Vik 2006, Elmhagen and Rushton 2007).

CONCLUSION

Being a mesocarnivore species red fox plays a crucial role in regulating prey populations and shaping the plant community structure by its deed dispersal ability, thereby contributing significantly to the maintenance of the food chain. Therefore considering the importance of this species it is vital to understand the influence of environmental predictors on its distribution for effective management and planning. The garbage sites are not only the source of food for red fox but also facilitate free ranging dogs which later on becomes feral and predate on red foxes. Hence management of red fox populations in high altitudes should take into account the availability of garbage sites and increasing population of stray dogs.

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AUTHORS CONTRIBUTION

A Sharief, LK Sharma, BD Joshi conceived the idea. V Kumar, R Dutta, H Singh, S Bhatacharya, AP Singh conducted field survey to collect data on Red fox. A Sharief performed the geospatial analysis and wrote the manuscript. LK Sharma, BD Joshi, M Thakur edited the manuscript. LK Sharma provided the logistic support.

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Ecological Niche Overlap between Himalayan Ibex and Livestock in the Jispa Valley of Trans Himalayan Landscape, Himachal Pradesh, India

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Abstract: The issue of livestock grazing poses a significant challenge to the long-term viability of wild ungulates. During the summer season, the Jispa valley of Lahaul and Spiti regions of Himachal experience a significant influx of migratory livestock and coexist and share habitat with the Himalayan Ibex. In the current study, employed the classification of Landsat 8 imagery to determine the land cover land use classes. The image classification achieved an overall accuracy of 82.96% and κ statistic value of 0.81. Species distribution of the Himalayan Ibex and livestock were performed using the Maxent modelling approach, with the utilisation of land cover classes and topographic parameters. The results of the identity test Schoener's D and Warren's I, demonstrate a noteworthy degree of overlap between the Himalayan ibex and livestock. Additionally, the Schoener's D and Warren's I background test indicates that the environmental conditions for Himalayan ibex and livestock are not entirely equivalent. Present study suggests the implementation of effective conservation plan to manage livestock and grazing areas for long-term survival of the wild ungulate species in the study landscape.

Keywords: Himalayan Ibex, Livestock, Image classification, Niche overlap

Globally, competition between wild ungulates and livestock is the most prevalent land utilization activity on a worldwide scale (Robinson et al 2014, Schieltz and Rubenstein 2016). Limitation of available resources used by species of the same trophic level leads to interspecific competition, which negatively affects species fitness. Competition between taxa *viz*. mammals, birds, fish, reptiles, and insecta is one of the most studied research areas (Bagchi et al 2004, Bergstrom and Mensinger 2009, Polo-Cavia et al 2009, Maron et al 2011, Zanni et al 2020). The competition between ungulates can be resource competition, in which species compete for shared space or food and another is interference competition where one species impacted the environment by some adverse effect, which reduces the environmental quality for another species (Birch 1957). Furthermore, the grazing activity of livestock is a serious threat to wild ungulates because the livestock outnumber wild ungulates, and the competition between wild and domesticated ungulates leads to multifaceted negative impacts on the trophic level. For millions of years, ungulates have been essential to maintaining higher trophic levels in ecosystems (Goderie et al 2013, Ripple et al 2015, Roberts et al 2021). The feces of ungulates act as natural fertilizer for the growth of seedlings (Hancock et al 2010, Faust et al 2011). Livestock grazing is also becoming a negative axis for reducing available fodder plants and the crucial habitat of wild ungulates by altering plant composition and structure (McIntyre et al 2017, Ren et al 2021) and trampling and grazing damaged the seedlings (Krzic et al 2006, Wassie et al 2009, Thakur et al 2011). It is evident that conflict between native ungulates and livestock is upsurge in many landscapes (Ren et al 2021). The Himalayan landscape has experienced pastoralism for a few eras. Every summer, enormous herds of sheep, goats, cattle, and equines migrate to the alpine meadows; in order to avoid the harsh cold, they brought back to lower elevations in the middle of autumn (Kittur et al 2010). Pastoralism and other disturbances have the potential to impact the nutritional balance of wildlife. These disturbances can result in increased energy expenditure as wild ungulates move away from the disturbance, potentially leading them to forage in suboptimal habitats instead of areas with higher-quality resources and, wild ungulates may face competition and be excluded from more favourable habitats (Schaller 1977). The significant number of rangelands in the Trans-Himalaya region are currently experiencing overstocking, leading to a notable

decline in livestock productivity (Mishra et al 2001). The shifting in habitat use, elevational and dietary niche of wild ungulates is altered by livestock grazing (Namgail et al 2009, Suryawanshi 2009). The wide range of habitats display diversified distribution pattern (Joshi et al 2020). The distribution range of the *Capra sibirica* is in the elevated areas of India, Kazakhstan, Uzbekistan, Afghanistan, Pakistan, Tajikistan, Kyrgyzstan, Mongolia, Russia, and China (Otgonbayar et al 2017). This species is commonly found in the Western Himalayan states of India (Joshi et al 2020). The Himalayan Ibex has been categorised as a "Near Threatened" species by the International Union for Conservation of Nature (IUCN) Red List (Reading et al 2020) and in India, it enjoys protection under Schedule I criteria under the Wildlife (Protection) Act of 1972. The Land cover Land use (LCLU) has a pivotal role in determining the habitats of any given species (Sherbinin 2002). The importance of satellite image classification for land cover categorization, have significant role in addressing societal needs related to managing natural resources, monitoring, and societal growth initiatives (Topaloğlu et al 2016, Khatami et al 2016). Image classification is a methodology that involves the categorization of individual pixels inside an image or raw image obtained from satellites used for remote sensing. The purpose is to provide suitable labels to distinct land cover categories (Abburu and Golla 2015). Furthermore, the impacts of pastoralism on wild ungulates in Trans-Himalaya is an important subject which have been studies from few decades. In this study, specifically investigated the geographical niche overlap that exists between Himalayan Ibex and livestock in the Jispa valley of the Lahaul-Spiti district, located in Himachal Pradesh.

MATERIAL AND METHODS

Study area: The present study area falls under the Jispa valley of Lahaul-Spiti district, Himachal Pradesh. This present study landmass situated in the eastern part of the district and lies from latitudes 32.5556° to 32.7626° N and longitudes 77.0294° to 77.3009° E (Fig. 1). This region is characterised by mountains adorned with snowcaps, gently sloping inclines, and limited vegetation. The region situated under the Trans Himalaya Ladakh Mountains (1A) Indian biogeographic zones and has a total size of 559 square kilometers. Summer and winter are the two prominent seasons of this area. In the summer season the inhabitants grow cash crops mainly peas, cabbage, potatoes and cauliflower, which is the main source of their livelihood. In winter frequent high snowfall occur in this area. Bhaga river intersected this area. Furthermore, this area is the home of many charismatic wild mammals.

Image classification and occurrence point of the Himalayan Ibex and Livestock: The Landsat 8 image was used to classify the LCLU using a supervised machine learning method based on a random forest algorithm (Rodriguez-Galiano et al 2012, Sonobe et al 2014) (Table 1). In this approach, decision trees are constructed individually and then combined in a random manner (Sonobe et al 2017,Thanh Noi and Kappas 2017). The image was categorised into nine distinct types, namely juniper patch, scrub, barren land, sparse vegetation, agriculture land, settlements, water, permafrost, and road. During the field survey, training data was collected from eight LCLU classes, excluding the permafrost class. The accuracy of the classification is determined by overall accuracy, kappa coefficient and F-statistics are utilised to assess the accuracy of the different categorised classes (Congalton 1991, Neetu and Ray 2020). The image classification was performed via the dzetsaka classification tool, which is integrated within the QGIS platform (Karasiak 2019). Furthermore, the collection of the occurrences of the Himalayan Ibex and livestock we employed camera trapping, trail sampling, direct observation and questionnaire survey. Nevertheless, due to the presence of terrain ruggedness, incline slopes, high peaked snowy mountains, and unpredictable weather conditions in the research region, we conducted representative sampling.

Variables preparation and selection: In this present study selection of ecologically pertinent variables and extracted Euclidean distance from each LCLU classes derived from

Table 2. Class accuracy metrices of Landsat 8 classified images using F – statistics

LCLU class	F-statistics
Agriculture	77.19
Sparse vegetation	87.06
Barren	82.93
Scrub	79.17
Juniper patch	74.53
Settlement	83.02
Permafrost	96.55
Water	90.70
Road	77.58

Table 1. Acquisition details for the Landsat 8 imagery

Satellite	Sensor	Path & Row	Acquisition date	Resolution (meter)	Scene ID
Landsat 8	OLI & TIRS	147 & 37	18-09-2022	30	LC81470372022261LGN00

classified Landsat 8 image. Moreover, used Alos Palsar, Digital elevation model (DEM) data and further the topographic variables calculated from this DEM data. Furthermore, generating all the variables resampled them at 30-meter spatial scale. A total of 16 variables were initially prepared for this present study (Table 3). In the process of constructing the final model, we opted to include solely uncorrelated variables based on Pearson correlation coefficients (r) that demonstrated a correlation coefficient exceeding 0.8.

Niche overlap: The ecological niche of the Himalayan Ibex and the livestock analyzed by the Maximum Entropy model (MaxEnt) (Phillips et al 2006). In order to conduct a comparative analysis of the expected distributions of Himalayan Ibex and livestock, we utilised the Environmental Niche Modelling (ENM) approach. Specifically, employed identity test and background test and two metrices Schoener's D and Warren's I indices, which have been recommended for ENM comparisons and were applied using ENMTools 1.1.1 (Warren et al 2021). This metric is widely recognized as a standardized tool for quantifying the relative similarity between observed niches, thereby enabling comparisons akin to percentage overlap (Rödder and Engler 2011, Broennimann et al 2012, Filz and Schmitt 2015). The measurement of potential distribution similarity is achieved by conducting a comparative analysis of corresponding values within individual cells of two grids. This similarity metric ranges linearly from 0, indicating a complete absence of similarity, to 1, signifying that the two grids under examination are entirely identical (Warren et al 2010).

RESULTS AND DISCUSSION

Image classification: The classification of Landsat 8 imagery by random forest algorithm shows overall accuracy of 82.96 and κ statistic 0.81 (Fig. 1), which depicts an overall good classification of this image. Furthermore, the accuracy estimation for classifying each feature class from this image by F- statistics depicts, all classes gain good accuracy when compared by ground-truthing data (Table 2).

Niche overlap result: The MaxEnt analysis yielded an acceptable Area Under the Curve (AUC) value, indicating its efficacy in predicting the spatial distribution of these ungulate species within this landscape. The estimated AUC for the Himalayan Ibex on the training data is 0.86, whereas the AUC for livestock on the training data is 0.92 (Fig. 2). The ecological niche of the Himalayan Ibex and livestock was assessed through the identity tests using two metrices, namely Schoener's D and Warren's I. The results of similarity test Schoener's D is 0.72 and Warren's I is 0.93. However, background tests results of environment similarity test of Schoener's D is 0.17 and Warren's I is 0.28. Therefore, the identity test reveals a significant degree of niche overlap between the wild ungulate and the livestock (Table 4, Fig. 3). The outcomes of the symmetric background tests, indicate that there is not a high resemblance between the ecological niches of the Himalayan Ibex and livestock in terms of environmental areas (Table 4, Fig. 4). The results of the symmetric background test indicate that the p-values for Schoener's D and Warren's I are both less than 0.05. This suggests that the null hypothesis is rejected, indicating a difference in the environmental space.

The livestock movement governed by the shepherd intervention, so their movement is restricted, moreover the livestock outnumbered the Himalayan Ibex, so the wild ungulate moves to this area where livestock not occupied. Bagchi et al (2004) found that Himalayan Ibex and livestock use the similar habitat properties and their diet also not different which indicate high degree of niche overlap. Another study found there are high activity overlap coefficient between Himalayan Ibex and livestock with Δ value of 0.80 (Salvatori et al 2021). Furthermore, Himalayan Ibex and its domesticated sympatric species (sheep and goats) shown the high degree of dietary overlap, which have detrimental effects on wild ungulates (Bagchi and Mishra 2006, Sharma et al 2015, Siraj-ud-Din et al 2016, Salvatori et al 2021). The relatively lower elevated region yields high-quality fodder

Table 3. Variables used for evaluating potential suitable habitat of Himalayan Ibex and livestock in the present study area

	Code	Variables
Land cover land use variables	Agriculture*	Agricultural areas distance
	Barren*	Barren land distance
	Juniper patch*	Juniper patch distance
	Permafrost	Permafrost areas distance
	Road	Road ways distance
	Scrub*	Scrub lands distance
	Settlement	Settlement distance
	Sparse vegetation*	Sparse vegetation areas distance
	Water*	Water lines distance
	NDVI*	Normalized difference vegetation index
Topographic variables	Elevation*	Elevation
	IMI	Integrated moisture Index
	Aspect*	Aspect
	CTI*	Compound Topographic Index
	Heatload	Heat load index
	Ruggedness	Ruggedness

'*' denotes used variables for Ecological Niche modelling

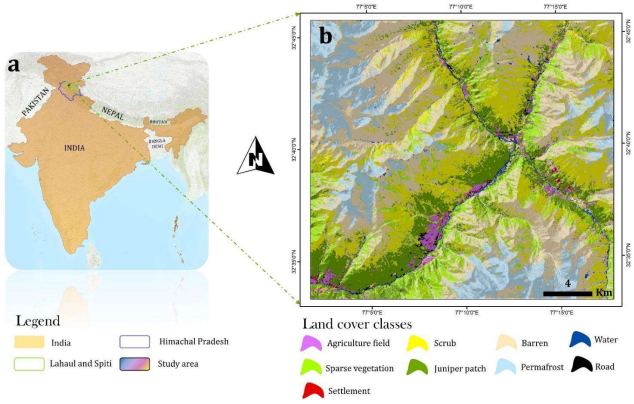

Fig. 1. Present study area location (a) and Landsat 8 classified image of the study area (b)

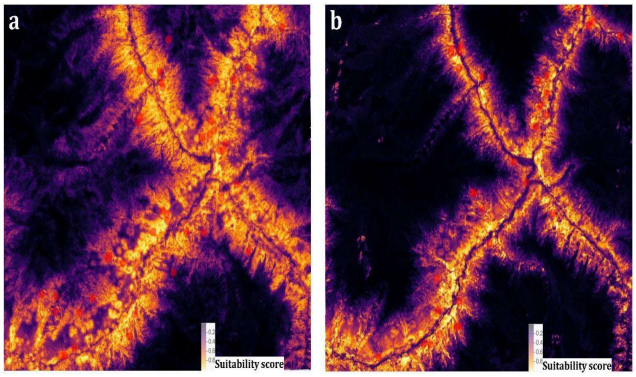

Fig. 2. Predicted suitable habitats of the (a) Himalayan Ibex and (b) livestock in the study area using MaxEnt modelling

Fig. 2. Predicted suitable habitats of the (a) Himalayan Ibex and (b) livestock in the study area using MaxEnt modelling

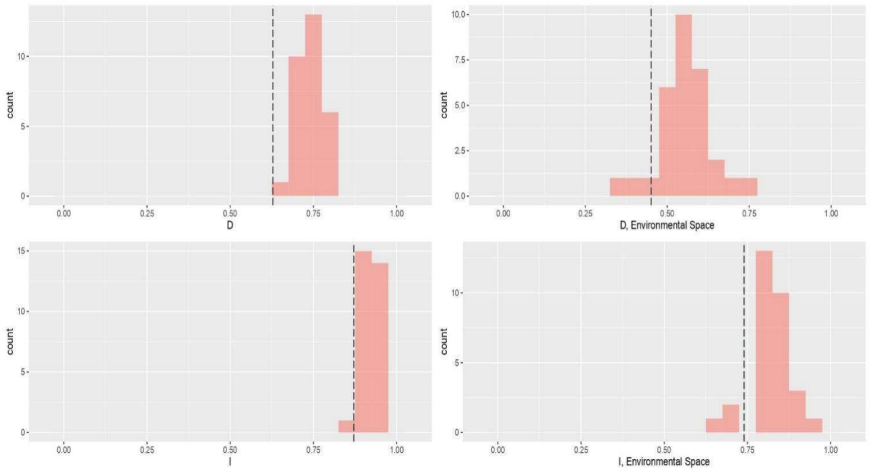

Fig. 4. Outcomes from the background test for the Himalayan Ibex and livestock across the geographic and environmental contexts. Histograms of 30 test simulations employing two distinct metrics, the Schoener's D and the Warren's I. The observed values showed by dotted lines

Table 4. p value of Niche overlap metrices, *viz.*Schoener's D and Warren's I of Identity test and background test

Metrices	D	I	env.D	env.I
Identity test	0.06	0.06	0.13	0.13
Background test	0.03	0.03	0.03	0.03

plant throughout the summer season, primarily utilised by livestock, thereby displacing the Himalayan Ibex from this location to habitats of inferior quality. Differentiation in resource usage facilitating co-existence and similarity in resource selection might cause competition (Voeten and Prins 1999, Bagchi et al 2003, Bagchi and Mishra 2006).The findings indicate that migratory goat and sheep populations in Jispa Valley contribute to spatial niche overlap with Himalayan Ibex, potentially posing a risk for disease transmission and pasture degradation (Khanyari et al 2022). Therefore, it is imperative that conservation management in Jispa Valley prioritises the resolution of the migratory grazing problem. Human – nature relationship is one of the well-known facts in recent world, human development and resource utilisation decline the natural balance, where Global Change Research human role is one of the key factors as a driving force (Holm et al 2013). Furthermore, the livestock grazing also reason of the retaliatory killing of the apex carnivores like snow leopard, wolf because of declination of natural prey like Himalayan Ibex and they hunt on livestock (Snow Leopard Network 2014, Mishra et al 2016, Salvatori et al 2021). Undeniably, livestock grazing plays a significant role in the economic livelihoods of local communities and shepherds. Consequently, it is imperative to closely monitor and manage livestock populations and implement effective pastoralism. These measures undoubtedly contribute to the preservation and maintenance of the natural wildlife population.

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AUTHOR CONTRIBUTION

R Dutta, BD Joshi, LK Sharma conceived the idea. R Dutta, H Singh, V Kumar, A Sharief conducted field survey. R Dutta**,** BD Joshi**,** LK Sharma performed the analysis. R Dutta, V Kumar spatial data preparation. R Dutta**,** BD Joshi**,** V Kumar,A Sharief, H Singh, LK Sharma wrote the manuscript. R Dutta**,** BD Joshi**,** V Kumar,H Singh**,** A Sharief, LK Sharma**,** M Thakur and R Babu edited the manuscript. LK Sharma and R Babu provided the logistic support and supervised the study.

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