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Prediction of Global Distribution of *Ganoderma lucidum* (Leys.) Karsten: A Machine Learning Maxent Analysis for A Commercially Important Plant Fungus

Manish Mathur and Preet Mathur[1*]

ICAR- Central Arid Zone Research Institute, Jodhpur-342 003, India
[1]Jodhpur Institute of Engineering and Technology, Jodhpur-342 802, India
**E-mail: preetm9535@gmail.com*

Abstract: The global habitat suitability of the fungus *Ganoderma lucidum* was simulated using the Maxent machine learning technique in relation to a number of environmental factors. 1159 geographically thinned *G. lucidum* presence points were projected over three bio-climatic time frames: current, 2050 and 2070, using four representative concertation paths (RCPs), namely 2.6, 4.5, 6.0 and 8.5 along with few non-climatic variables like eecosystem rooting depth and rooting zone water storage size and ssurface soil characteristics. With these climatic and RCPs projections, areas under the receiver operating curve (AUC) were reached 0.90, suggested the excellent predictive qualities of the modelling. Based on Maxent output, habitat suitability types were identified using the ARC-GIS raster calculator tool, which provided optimum, moderate, marginal, and low suitability classes. The largest optimum habitat for this fungus was detected during current bioclimate time-frame, measuring 2983977.56 square kilometres, while smallest area (600355.52 square kilometres) under this niche type was recoded under 2050 RCP 6.0. By doing so, percent changes in each habitat class from their respective current to future projections were estimated and our analysis revealed -41.82 to -79.88 percent reduction for the optimum habitat areas. The Permutation Importance value indicated that energy/temperature variables have a much greater influence on this species' global niche distributions than do water variables, and these variables were identified as important predisposing factors for this fungus. Secondary predisposing variables for this fungus included an eight-centimetre ecosystem rooting depth and soil organic carbon levels of up to 145 (g/kg). From present study, it can deduce that this fungus is always present in specific European countries. However, both optimum and moderate habitat suitability for this species will deteriorate within Asian countries, making wild collection for various medicinal product synthesis more difficult. As a result, its availability in such areas will be heavily reliant on its in-vitro conditions (substratum) as well as the adjustment of micro-environmental variables identified in this work.

Keywords: *Ganoderma lucidum,* Ecological Niche Modelling, Maxent analysis, Bio-climatic variables

Ganoderma is a genus of white-rot polypore fungi in the Ganodermataceae family that is distinguished by the development of a double-walled, generally echinulate basidiospore. *Ganoderma lucidum* can be found all over the world (Oke et al 2022). *G. lucidum* has been recognized as the major pathogen on tree species such as *Quercus spp., Cocos nucifera, Camellia sinensis, Prunus persica, Prosopis cineraria, Acacia tortalis, A. senegal, A. nilotica, A. catechu, Albizia lebbeck, Azardirachta indica, Casuarina equisetifolia.* Basal rot has killed *Prosopis cineraria* and *Acacia tortalis* trees in India's dry and semi-arid regions (Schuch and Kelly, 2007, Bhansali 2012) (Fig. 1). Despite being a wood-rotting mushroom, it also has antibacterial, antifungal, and antiviral (especially against herpes and HIV) as well as anticancer, anti-inflammatory, antioxidant, and radical scavenging qualities (Sudheer et al 2019). *G. lucidum* supplements are being marketed as food and medication supplements to improve immune system and metabolic performance. Frequently sold items include coffee, powdered tea, dietary supplements, beverages, syrups, toothpastes, soaps, and other similar products (Singh et al 2013). Because *Ganoderma* extract inhibits the tyrosinase enzyme, which stops the skin from producing melanin, it can be found in a variety of facial and cosmetic products (Hyde et al 2010). Due to its ability to reduce dihydrotestosterone and prostatic hyperplasia, it is also used to improve male hair (Meehan, 2015). Around 200 *Ganoderma* medications and over 1,000 other products are available (Chan et al 2021). Products made from *G. lucidum* are thought to be sold for more than 2.5 billion USD annually in Asian nations like China, Japan, and South Korea (Bijalwan et al 2020).

The market for nutraceuticals based on *Ganoderma* is expanding quickly in India, and is expected to reach $25 million USD in 2023 (El Sheikha et al 2022, Fatima et al 2022, Bijalwan et al 2021). On online marketplaces like Amazon, Flipkart, and others, a variety of genuine and verified *Ganoderma*-based products are readily available (www.vegamebeljepara.com; www. dazzlinggroup.com; www.dxnmalaysia.com and www.vegamebeljepara.com; Wu et al 2018). Figures 1d and 1e exhibit *G. lucidum*

Fig. 1. *Ganoderma lucidum* on *Prospois cineraria* (A) and on *Acacia tortalis* (B*: photo courtesy by Dr. R.K. Bhansali). Dying of tree with infection of *G. lucidum* (C), fruiting bodies collected from filed (D) and health care product with *G. lucidum* as an active ingredient: E, https://vegandukan.com/products/zindagi-ganoderma-pure-extract-capsules-helpful -in-weight-loss-increase-energy-stamina?variant=39433736552634&currency=INR&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_org (Jhanil Healthcare Pvt Ltd)

basidiocarps and its commercial product. There has been an effort to artificially cultivate this fungus due to the difficulty in finding it in the wild and the rising demand for its raw material on the global market (Bijlwan et al 2021). *G. lucidum* is primarily produced by solid-state fermentation, and the fruiting body develops over the course of about six months (Magday et al 2017). Alternative methods of fungi cultivation are required because the process is cumbersome and difficult to control (Yang et al 2019, Subedi et al 2021).

This ecological niche modelling was done with the help of the machine learning Maxent tool, which is a non-parametric Java-based application. From such analysis it was anticipated that such test facilitate scientific communities to understand how much space on the world is suitable for this species to grow in, based on bioclimatic and soil factors, as well as other factors related to rooting depth, total plant accessible water storage capacity. The study's findings add to the concern over how much *G. lucidum* material will be available from the wild under various climate change and greenhouse gas scenarios, which may be related to the need for its *in-vitro* production to meet industrial demands.

MATERIAL AND METHODS

Data collections: Distributional records for *G. lucidum* were obtained from data repositories such as the Global Biodiversity Information Facility (www.gbif.org/), the Indian Biodiversity Portal (https://indiabiodiversity.org/species /show/33318), published literature (Khara 1993, Khara and Singh 1997, Pilotti, 2005, Bhansali 2012, Basnet et al 2017, Bijalwan et al 2021, Shah et al 2021) and from field-based inventories (Jindal et al 2009 and 2010). The coordinates of these sites were identified on a WGS84 coordinate datum system using high-resolution Google Earth satellite image data and GIS ArcMap (Coban et al 2020) software. Furthermore, where occurrence data was unavailable, exact geo-coordinates were obtained by determining latitude and longitude values using Google Earth (http://ditu.google.cn/). Using the aforementioned sources, the distributional localities were assembled into a CSV database (.csv). To reduce spatial autocorrelation and duplicate records, and filtered our data set using the Spatial Thin window of the R-based Graphical User Interface Wallace Software (Kass et al 2018) with a thinning distance of 10 kilometers.

Bio-Climatic (BC) and non-bioclimatic variables: Based on where species are now, machine learning approaches can predict where they will be in the future (Philliips and Dudik 2008, Mathur and Mathur 2023). The bioclimatic variables used to estimate current and future distributions were taken from observational data in WorldClim ver. 1.4, which may be found online at https://worldclim.org/data/cmip6/cmip6clim30s.html (accessed on 21st August, 2022). 19 bioclimatic variables (Hijmans et al 2001, Kass et al 2018) were downloaded and converted to ASCII (or ESRI ASCII) in DIVA-GIS version 7.5 (Coban et al 2020, Ye et al 2020) for current as well as two future climatic scenarios (2050-time frame that represents the mean values from 2041 to 2060 and 2070-time frame that represents the mean values from 2061 to 2080 (Zhang et al 2021). These were downloaded pertains to four RCPs, namely RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Details of each bio-climatic parameter, along-with their units and mathematical expressions are presented in Table 1.

Seven different soil parameters (bulk density kg/cm^3, cation exchange capacity cmol kg^{-1}, soil pH H_2O, sand percent, silt percent, clay percent contents, soil organic carbon stock g kg^{-1} and soil Nitrogen cg/kg from surface soil) were downloaded from the ISRIC World Soil Information database https://isric.org/soilgrids (Accessed on 15th August 2022). These data sets were obtained and processed through WMS servers using ArcMap. (Full instructions are available at https://www.isric.org/instruction-wms.html Cotrina Sánchez et al 2020).

Terrestrial Observation Panel for Climate of the Global Climate Observation System (GCOS) identified the 95% rooting depth as a key variable needed to quantify the interactions between the climate, soil, and plants. International Land Surface Climatology Project (ISLSCP) provided the data on vertical root distribution that encompasses data points from various land covers like (evergreen needleleaf forest, evergreen broadleaf forest, deciduous broadleaf forest, mixed forest, wooded grassland, cropland, urban built-up and open shrubland, closed shrubland, bare ground (Schenk et al 2009). Data on this parameter was downloaded from http://daac.ornl.gov

ISLSCP II: total plant-available soil water storage capacity of the rooting zone provides estimates of the geographic distribution of the total plant-available soil water storage capacity of the rooting zone (rooting zone water storage size) on a 1.0^0 global grid (Kleidon 2011) https://daac.ornl.gov/ISLSCP_II/guides/root_water_storage_1deg.html. In the present study, utilized rooting zone water storage (mm H_2O) derived from assimilation of NDVI-fPAR (fraction of Absorbed Photosynthetically Active Radiation) and atmospheric forcing data. Further data-set on global croplands and pasture lands were downloaded and utilized as per the procedure provided by Ramankutty et al (2010a and b).

Issue of multicollinearity: The Pearson Correlation Coefficient (r) was used to investigate cross-correlation, and a multicollinearity test was run to check for over-fitting. In addition, variables with cross correlation coefficient values larger than or equal to 0.85 were gradually removed (Pradhan 2016) using the Niche Tool Box (Osorio-Olivera et al 2020 https://github.com/luismurao/ntbox). Following the procedures recommended by Kumar et al (2006), multi-collinearity among predictor variables was decreased. One significantly cross-correlated variable that is biologically relevant to the species and makes model interpretation simple was chosen from two others (Padalia et al 2014; Mathur and Mathur, 2023). For instance, it was found that the variables yearly precipitation and precipitation of the wettest month had a strong correlation, then chose to keep the latter variable because it depicts seasonal variability in precipitation. For further analysis, only one variable from each group of strongly correlated variables (r^2 > 0.85) was preserved. In this study, model training and model validation were assigned to 70% and 30% of the data, respectively (Obiakara and Fourcade 2018).

Projection correction: Because the Bio-Climatic (BC) and Non-BC variables were obtained from different sources and at different resolutions, their projections should be corrected before extracting data and predicting the ensemble model. This was accomplished through the use of a series of steps in ArcMap using ArcToolbox. First, defined the projection in Data Management Tools' "projection and transformation" sub-window then used the WGS 1984 EASE Grid Global Projected Coordinate System for this. Using the Raster Project Tab, the

Table 1. Predictive variables (Current and future) bio-climatic data variables. Calculation criterion of each variable (https://pubs.usgs.gov/ds/691/ds691.pdf)

Code	Environmental variables	Scaling factor	Unit
BC-1	Annual mean temperature	10	°C
BC-2	Mean diurnal range (Mean of monthly (max temp - min temp)	10	°C
BC-3	Isothermality (BC2/BC7) (×100)	100	Per cent
BC-4	Temperature seasonality (standard deviation ×100)	100	-
BC-5	Max temperature of warmest month	10	°C
BC-6	Min temperature of Coldest Month	10	°C
BC-7	Temperature annual range (BC 5-BC 6)	10	°C
BC-8	Mean temperature of wettest quarter	10	°C
BC-9	Mean temperature of driest quarter	10	°C
BC-10	Mean temperature of warmest quarter	10	°C
BC-11	Mean temperature of coldest quarter	10	°C
BC-12	Annual precipitation	1	mm
BC-13	Precipitation of wettest month	1	mm
BC-14	Precipitation of driest month	100	mm
BC-15	Precipitation seasonality (Coefficient of variation)	1	Per cent
BC-16	Precipitation of wettest quarter	1	mm
BC-17	Precipitation of driest quarter	1	mm
BC-18	Precipitation of warmest quarter	1	mm
BC-19	Precipitation of coldest quarter	1	mm

first step's output was reprojected with the same coordinate system, as well as the default resampling technique (Nearest neighbour assignment) and output cell size.

Species distribution modelling: In this study, the Maxent 3.4.1 software (http://www.cs.princeton.edu/schapire/Maxent/) was used to simulate and predict the potential geographical distribution probability of *G. lucidum* under current and two futures (2050- and 2070-time frame) scenarios (Coban et al 2020, Ye et al 2020). During the modelling process, 70% of the 1159 *G. lucidum* distribution data samples were randomly selected as training data, while 30% were used as testing data. The number of background points generated at random, was set to 10,000 (Zhang et al 2021). To avoid over-fitting of the test data, set the regularization multiplier to 0.1. (Phillips et al 2006) and used linear, quadratic, and hinge properties. A total of 100 runs were planned for model building (Flory et al 2012). In the environment parameter settings, Jackknife method was applied, and the other parameter settings were left at the software defaults. The performance of this model was evaluated based on the computed receiver operating characteristic (ROC) curve and the area under the curve (AUC). In general, AUC values vary from 0.5 to 1, which could be divided into five classes: fail (0.5–0.6), poor (0.6–0.7), fair (0.7–0.8), good (0.8–0.9), and excellent (0.9–1, Zhao et al 2021). The closer the AUC value was to 1, the farther away from the random distribution, the greater the correlation between environmental variables and the predicted geographical distribution of species, and the more accurate the performance of the model, while AUC < 0.5 is a contingency difference, which can be regarded as a stochastic forecasting model, and rarely happens (Hanley and McNeil 1982).

Post Ensemble Analysis

Habitat suitability: Raster outputs (ASCII) of the Maxent model were imported to ArcMap, and distinct habitat types for this species were defined based on their cell values (0 to 1). Follow the criteria of constant point break for each class (Khan et al 2022) kept a, resulting in four suitability classes: optimum, moderate, marginal, low and absent or inappropriate. Area (sq. km.) under these classes was quantified by using the raster calculator tool (spatial Analyst Tool/Map Algebra/Raster Calculator). To figure out how the different climate scenarios would affect the predicted habitat suitability, used the following formula to measure the percent change in mean habitat suitability under optimum class (Mathur, 2014a, Wright et al 2016, Kaky et al 2020).

$$\left[\left(\frac{\text{Future - Current}}{\text{Current}}\right)\times 100\right]$$

RESULTS AND DISCUSSION

Data processing and multicollinearity: The 1686 records were collected for this species from various sources around the world, and filtered out all but one occurrence of a specific record in a given location using the Spatial Thin window of R language-based Wallace Software's (Kass et al 2018) with a thinning distance of 10 kilometers. To complete the ENM development process, 1159 reports of the presence of *G. lucidum* were gathered. Results of correlation analysis among different bioclimatic variables are presented in Table 2. To address the issue of multicollinearity in species distribution modelling, employ the approaches proposed by Kumar et al (2006) and Pradhan et al (2016). BC-2 and BC-19 were significantly correlated with other bioclimatic variables during current and all predictive RCPs with 2050 and 2070. Precipitation of Warmest Quarter (BC-18) was the least correlative with other BC variables and hence that was utilized for ENM analysis of this species with all RCPs. Such trends were also recorded with Isothermality (BC-3) and Mean Temperature of Wettest Quarter (BC-8) except 2050 RCP 2.6 and 2070 RCP 8.5, respectively. Contrary to above trends, Annual Mean Temperature (BC-1) and Temperature Seasonality (BC-4) were utilized for analysis only during 2050 RCP 2.6. Among soil variables, CEC, nitrogen and silt contents exhibits significant correlations with other variables and hence, they were eliminated from further analysis.

The analysis of omission-commission plots demonstrates the effect of cumulative threshold selection on anticipated area as well as autocorrelation of sample points (test and training). The omission rate of the test sample should ideally be similar to the projected omission rate (Djebbouri et al 2021). Trends in such graphs can be explained by two criteria: higher omission rates on test samples than expected omission rates, showing independence between test and training data. Such findings show that spatial autocorrelation has no influence on the models. In certain cases, the test omission line is significantly lower than the predicted omission line, indicating that the test and training data are not independent and are derived from the same spatially autocorrelated presence data.

In this study, majority of predictors, our test omission lines are well matched with projected omission (Fig. 2), indicating that there is no autocorrelation in sampling and that our model attributes are not affected by sampling bias. However, for some variables, like as surface soil properties, 2050 RCP 4.5 and 2070 RCP 8.5 omission test lines are lower than the projected omission line showed some form of spatial association.

Predictors contributions: With 30.9% and 33% permutation relevance, annual precipitation (BC-12) was determined as the most important controlling element for this species during current and 2050-RCP 4.5. Similarly, for 2050 RCP 6.0 and 8.5, the minimum temperature of the coldest month (BC-6) has the largest permutation relevance of 40.7 and 35.9%, respectively. The isothermality (BC-3) is the most essential factor for this species during 2070, with RCP 2.6 (40.3%), 4.5 (38.8%), and 6.0 (30.5%) being the greatest permutation importance values for the three greenhouse scenarios (Table 3). Temperature Seasonality (BC-4) with 37.7% PI and Precipitation of Wettest Quarter (BC-16) with

Table 2. Outputs of multi-collinearity tests conducted for different climatic data-sets. √ = use for analysis and x remove from analysis as they have significant correlation with other variables

Variables	Current	2050				2070			
		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
BC-1	x	√	x	x	x	x	x	x	x
BC-3	x	x	√	√	√	√	√	√	√
BC-4	x	√	x	x	x	x	x	x	x
BC-5	√	x	√	√	√	√	√	x	√
BC-6	√	x	√	√	√	x	x	√	x
BC-7	√	√	x	x	x	√	√	x	x
BC-8	x	√	√	√	√	√	√	√	x
BC-9	x	x	√	√	√	√	x	√	x
BC-10	x	x	x	x	√	x	x	√	x
BC-11	√	x	x	x	x	x	x	√	x
BC-12	√	√	√	x	x	x	x	x	x
BC-13	√	x	x	x	x	x	√	√	x
BC-14	x	√	√	√	x	√	x	√	√
BC-15	√	x	x	x	√	√	√	√	√
BC-16	x	√	√	√	√	√	x	x	√
BC-17	x	√	√	√	√	x	x	x	x
BC-18	x	√	√	√	√	√	√	√	√

BC-2 and BC-19 were excluded from all analysis

Table 3. Permutation Importance (PI) calculated from Maxent analysis for bioclimatic environmental variables over three climatic time periods

Bio-climatic variables	Current (PI)	2050 RCPs				2070 RCPs			
		2.6	4.5	6	8.5	2.6	4.5	6	8.5
BC-1	-	15.1	-	-	-	-	-	-	-
BC-3	-	-	31.3	35.5	29.9	40.3	38.8	30.5	31.5
BC-4	-	37.7	-	-	-	-	-	-	-
BC-5	21.9	-	10.8	5.9	3.9	-	12.9	-	7.5
BC-6	6.6	-	13.6	40.7	35.9	10.9	-	3.8	-
BC-7	8.1	9.4	-	-	-	14.3	23.8	-	-
BC-8	-	4.8	4.5	1.5	0.6	3	1	3.6	-
BC-9	-	-	2.2	1.9	1.7	6.1	-	4.7	-
BC-10	-	-	-	-	6	-	-	11.6	-
BC-11	16.8	-	-	-	-	-	-	24	-
BC-12	30.9	25.7	33	-	-	-	-	-	-
BC-13	7.1	-	-	-	-	-	18	17.9	-
BC-14	-	0.2	0.4	0.4	-	1.1	-	0.2	6.8
BC-15	8.7	-	-	-	1.6	4	4.4	2.3	4.7
BC-16	-	4.6	2.2	12.2	0.8	19	-	-	35.9
BC-17	-	1.1	1.6	0.4	18.3	-	-	-	-
BC-18		1.3	0.4	1.5	1.4	1.3	1.1	1.4	13.6

35.9% PI were identified as the most influential predictors with RCPs of 2.6 and 8.5 in 2050 and 2070, respectively. Most RCPs found Precipitation of Driest Month (BC-14) as the least effective factor, followed by Precipitation of Warmest Quarter (BC-18). Among the non-climatic variables, ecosystem rooting depth (85.8%) and soil organic carbon (PI 74.5%) were identified as the most important and influential parameters for this species (Table 4).

Model performance: The area under the receiver operating curve (AUC) was used to evaluate the Maxent model's performance for predicting distribution of this species. The machine learning method performs excellently (AUC = 0.94) with the current bio-climatic timeframe (Fig. 3), but it performs poorly (AUC = 0.78) with ecosystem rooting depth and rooting zone water storage capacity and was good (AUC > 0.80) with surface soil attributes (Fig. 3). The present model's quality was high, with AUC values more than 0.90 for two future bio-climatic timeframes and four greenhouse gas scenarios. Figure 4 depicts the Jackknife test results with multiple predictors. These horizontal lines showed the variables with

Table 4. Permutation Importance (PI) calculated from Maxent analysis for non-bioclimatic environmental variables

Predictors	Permutation values
Ecosystem rooting depth	85.8
Rooting zone water storage size	14.2
Surface soil properties	
Soil organic carbon	74.5
Sand	6
pH	8.1
Soil bulk density	7.4
Clay contents	4

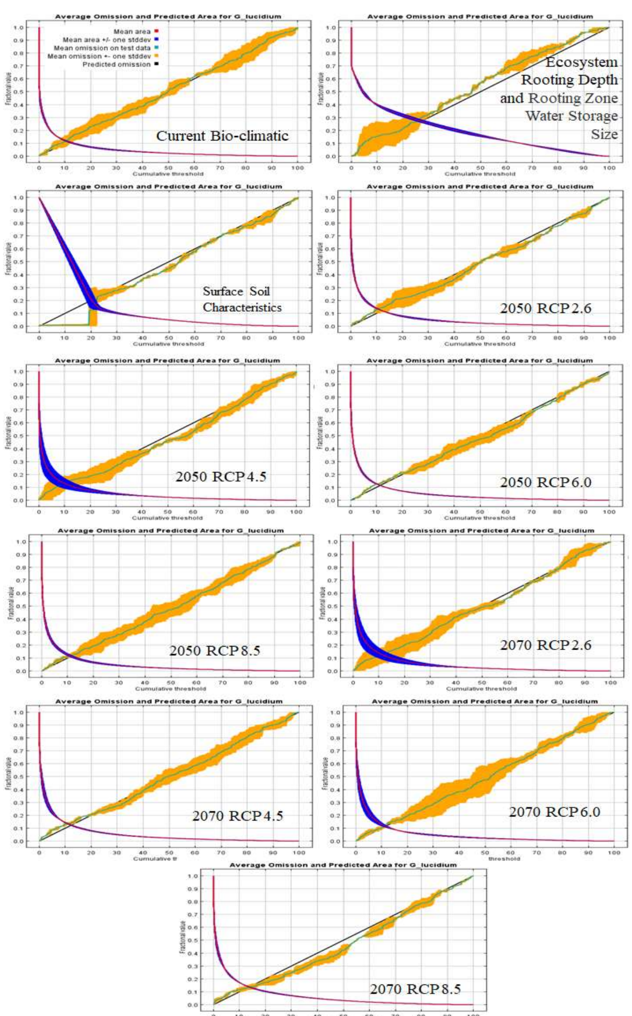

Fig. 2. Analysis of omission/commission with various bio-climatic timeframes and RCPs projection and non-climatic variables

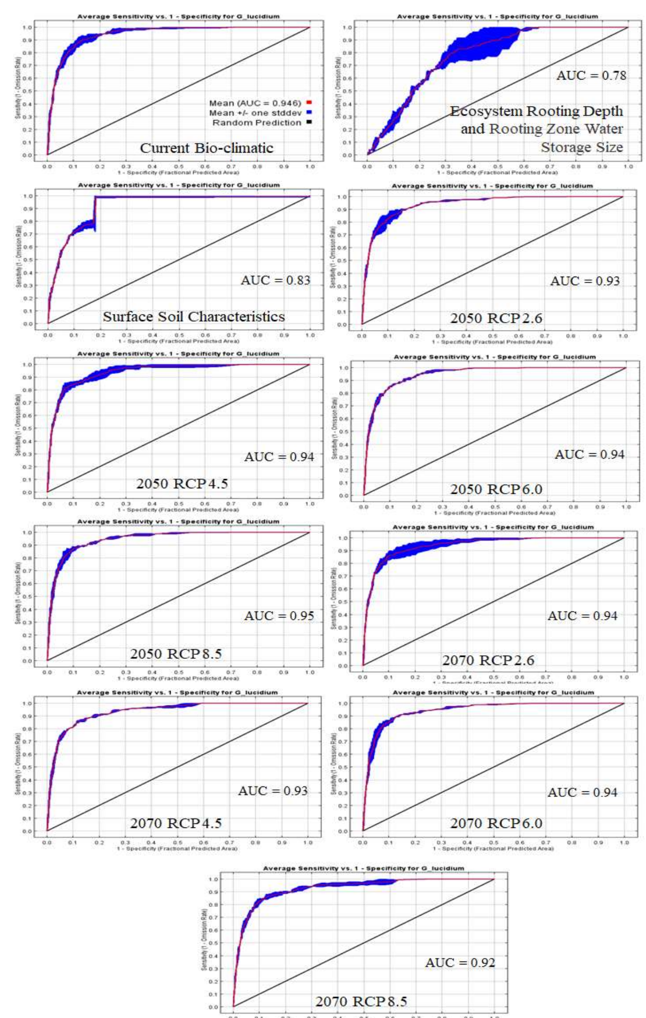

Fig. 3. Receiver Operating Characteristic (ROC) curves: with various bio-climatic timeframes and RCPs projection and non-climatic variables

the greatest gain when used alone, and hence appear to have the most significant information on their own (such variables can be referred as category 1 variables). The variables that reduce the gain the most when eliminated, and so appear to contain the most information that other variables do not category 2 variables. This study unearthed that the bio-climatic variables like mean temperature of coldest quarter (BC-11) functioned as category-1 variables for the current and 2070 RCP 6.0 time-frames, whereas the variables Maximum Temperature of Warmest Month (BC-5) and Isothermality (BC-3) functioned as category-2 variables for the same time-frames. In the 2050 RCP 2.6 and 2070 RCP 4.5 climatic projections, characteristics such as mean temperature of wettest quarter (BC-8) and isothermality (BC-3) were designated as category-1 variables. The identical catogry-1 (minimum temperature of coldest month: BC-6) and catogry-2 (Isothermality) characteristics that influenced the occurrence of this species during their respective climatic and RCP projections will exist during 2050 climatic timeframes (RCP 4.5, 6.0, and 8.5). RCP 8.5 of 2070 and non-climatic variables such as ESRD and WS, as well as soil properties, have category 1 and category 2 variables that are similar.

Trends of habitat suitability with respect to various significant category-1 predictors: The occurrence frequency of *G. lucidium* fluctuates as a function of major climatic, rooting depth, root zone water storage capacity, and surface soil variables depicted in Figure 5. The habitat suitability was higher toward the mean temperature of the coldest quarter (BC-11), and the maximum of habitat suitability with this predictor remained at temperatures -10 to +10^0 C for current climatic conditions (Fig. 5a) and -10 to 5^{0}C at 2070 RCP 6.0 (Fig. 5h). Minimum temperature of coldest month (BC-6) was best suited for this species with a range of -10 to +10^0 C with RCP 4.5 of 2050 (Figure 5c) and -10 to +8^0 C with RCP 4.5 (Figure 5d) and 6.0 (Fig. 5e) of the same time-frame. While its habitat was altered by Isothermality at a range of 20 to 40% during 2070 RCP 4.5 (Figure 5h) and 8.5 (Figure 5i), its suitability fell dramatically after these threshold values. Interestingly, during the RCP 2.6-time frame of 2050 and 2070, the mean temperature of the wettest quarter (BC-8 Fig. 5b) and the mean temperature of the driest quarter (BC-9 Figure 5f) were shown to be more beneficial for this species. However, their peak widths differed, 2050 peak width was recorded as being more border than 2070 peak width. With characteristics such as ecosystem rooting depth, this species' habitat preferentiality was continuously synchronised and reached a maximum of 8 cm before drastically decreasing (Fig. 5j). Similarly, soil organic carbon up to 145 (g/kg) was determined as most beneficial to this fungus's habitat suitability (Fig. 5k).

Spatial delineation of range contraction or expansion: Table 5 displays the spatial extent (in square kilometres) of various habitat types based on climatic (present and future estimates) and non-climatic variables. The largest area under the optimum habitat class (2983977.56 sq. km.) was recorded with current bio-climatic time-frame, while the lowest area (600355.52 sq. km) under this class was recorded with 2050 RCP 6.0. Similarly, maximum area under moderate (41829161.24 sq. km) and marginal (43356903 sq. km) habitat classes were recorded with ecosystem rooting depth and rooting zone water storage size. However, minimum areas under these classes were recorded with 2050 RCP 8.5 and surface soil properties, respectively. The later variables (soil) can support only its lower habitat type covering 108528601.18 sq. km area. Overall, under all classes, maximum total area (115217353.3 sq. km) was

Table 5. Area (sq km) of different habitat suitability classes with different climatic and non-bioclimatic predictors

Predictors	Area (Sq. Km.) under habitat suitability classes				
	Optimum	Moderate	Marginal	Lower	Total
Current BC	2983977.56	8735251.80	13418953.33	34299321.62	59437504.32
Surface soil properties	2098660.69	2080085.48	2050899.83	108528601.2	114758247.2
Root and water	2926892.06	41829161.24	43356903	27104397	115217353.3
2050 RCP 2.6	1735993.21	4280904.28	4280904.28	13527374.83	23825176.6
2050 RCP 4.5	969631.30	1910274.91	4588175.75	11671040.62	19139122.59
2050 RCP 6.0	600355.52	1721083.65	4334096.50	10743475.03	17399010.71
2050 RCP 8.5	674798.4962	1346748.766	3714953.407	9700582.672	15437083.34
2070 RCP 2.6	640858.7371	1645626.473	3840950	14072832.65	20200267.86
2070 RCP 4.5	829087.6135	1656671.308	3900602.178	15210570.79	21596931.89
2070 RCP 6.0	678794.6695	1657296.388	4375988.385	9631468.338	16343547.78
2070 RCP 8.5	1070867.593	3333235.379	8576820.252	16455387.61	29436310.83

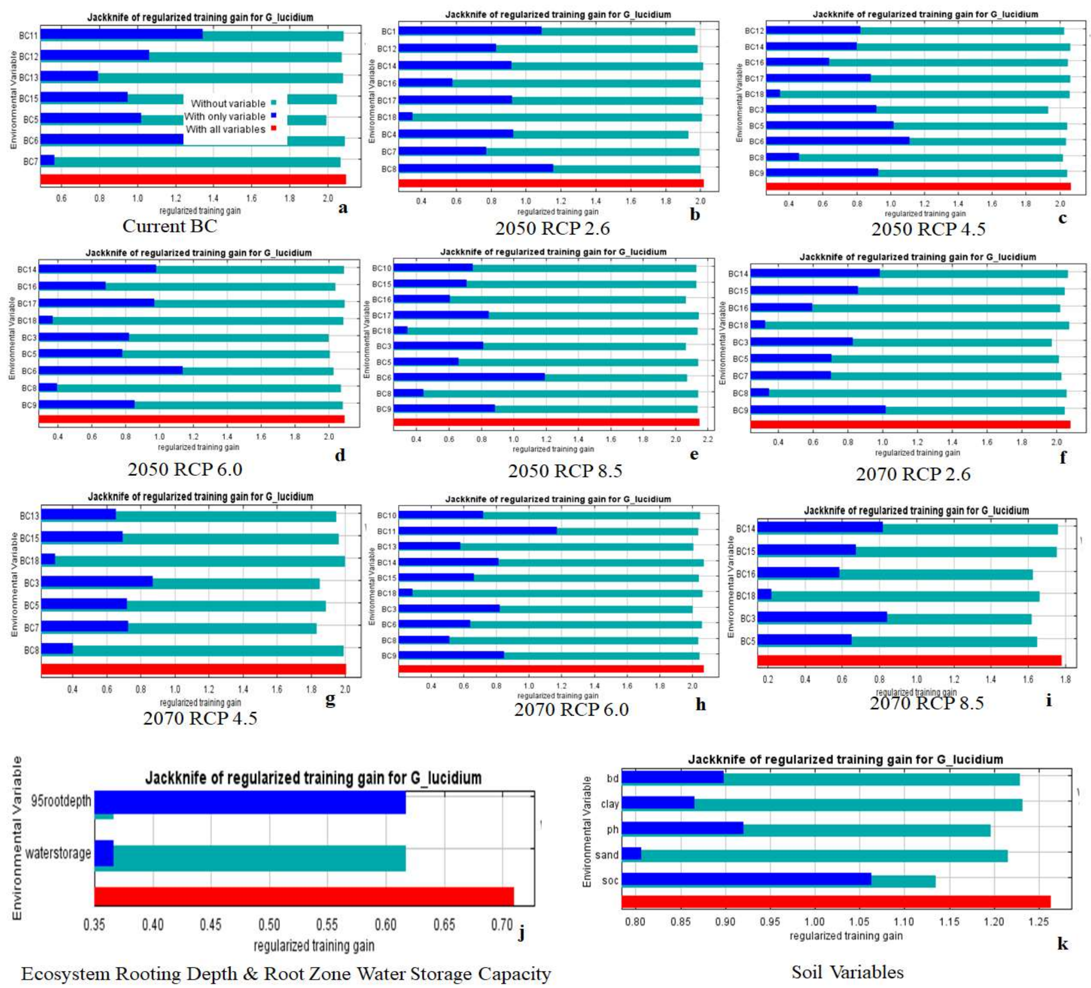

Fig. 4. Jackknife test of training data set to identified of variables with maximum gain and loss in model qualities

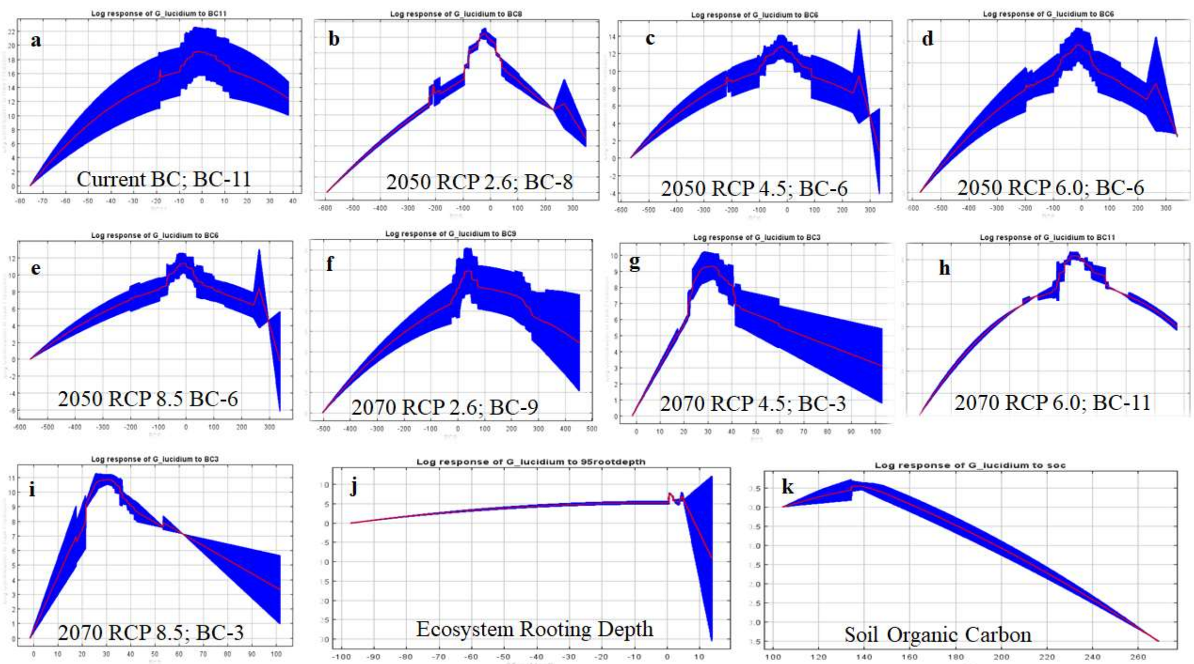

Fig. 5. Response curves with various climatic and non-climatic parameters illustrating the likelihood of *G. lucidum* habitat suitability

recorded with rooting variables, while the overall lowest area under all classes (15437083.34 sq. km.) was recorded with 2050 RCP 8.5. Further, percent changes for the area under different habitat classes (through climatic variables only) with respect to current areas under these classes. Our analysis suggested that optimum habitat class for *G. lucidum* will be reduced by - 41.82 (2050 RCP 2.6) to -79.88 (2050 RCP 6.0 Table 6) compared to its current area. Similarly, moderate area reduced from -50.99 (2050 RCP 2.6) to -84.58 (2050 RCP 8.5). Such trends were also recorded for marginal and low habitat types also. Such result indicates that this species will lose its area under all types of habitats with studied climatic and non-climatic predictors.

Spatial extent of optimum class: KML analysis of the ASCII file of the maxent output suggested that the optimum areas within current climatic conditions are located in southern India, including Karnataka (Tilvalli, Anavatti, Hosakawali, Hebri, Varanga, Bramavara, Belve, Thenka Bettu, and Kundapura), Maharashtra (Tilvalli, Anavatti, Hosakawali, Hebri, Varanga, Bramavara (particularly Ratnagiri, Kolhapur, Goa, Belagavi, Pune and Mumbai). Various marginal areas can also be found in western portions of the country, such as Gujarat (Tharad, Bhuj, Somnath, Porbandar, Bhanvad), Rajasthan (Sanchor, Bhinmal, Jalore, Pali, Malpura, Jhalawar, Guna), and some districts of Uttar Pradesh and Madhya Pradesh (Fig. 6). The greatest region is classified as optimal, and it includes primarily European countries such as the United Kingdom, Denmark, the Netherlands, Poland, territories next to the Baltic Sea, and patches in Germany and Switzerland. It can see from Google Earth that these countries provided optimal to moderate conditions for this fungus (Fig. 7). Current non-climatic characteristics, such as ecosystem rooting depth and root zone water storage capacity, revealed increasingly dispersed optimum categories around the world, including India, China, Zimbabwe, the Democratic Republic of the Congo, Hungary, Brazil, and some states in the United States (Figure 6 and 7). The surface soil parameters indicated that there was greater land under marginal and low suitability for this fungus. Using these non-climatic characteristics, optimal regions were identified in Belarus, Poland, Norway, Sweden, Finland, Chhattisgarh, sections of Maharashtra (Nagpur, Pune), and several states in the United States of America.

With a predicted climatic time-frame of 2050 and RCP 2.6, there will be a decline in optimum areas from Indian continents (Fig. 8), and this fungus will be found in isolated spots in southern India. Our findings also demonstrated a significant decline of this fungus in the European region, which will be predominantly exhibited in Denmark (Fig. 9). However, with RCP 4.5 and a similar climatic time frame, a somewhat larger area under the optimal class, notably covering Italy and parts of Georgia. Furthermore, the least area under this class will occur if RCP 6.0 (2050) operates, and within India, few isolated patches will occur only in the south, while the largest area under this class will remain in Denmark and neighbouring areas. In terms of the area under the optimum class, if RCP 8.5 is implemented (2050), a similar situation will be maintained, and our analysis suggests that isolated optimal areas in India's southern and western parts will be transformed to low suitable areas. However, a new optimal class area would arise in the country's eastern section, Meghalaya. Similarly, the highest area in this category will stay in Denmark, with no increase in size in the Denmark parts toward Sweden (Fig. 9). With 2070 RCP 2.6, the optimum area will fall drastically in comparison to current climatic conditions (Fig. 10), and within India, just a few isolated patches (Maharashtra and Karnataka) and two patches at Rajasthan will be detected (one new Mount Abu and one near Ajmer district). Our examination of European countries clearly shows that the majority of the optimum areas in Belgium, the Netherlands, and the United Kingdom will be converted to the moderate category (Fig. 11). A large patch of low habitat suitability will be detected in China during this GHG period. However, there will be a rise in area under

Table 6. Per cent changes under four studied habitat suitability classes with two bio-climatic timeframes and four RCPs with respect to current bioclimatic conditions

Bio-climatic time frames and RCPs	Optimum	Moderate	Marginal	Low
2050 RCP 2.6	-41.82	-50.99	-68.10	-60.56
2050 RCP 4.5	-67.51	-78.13	-65.81	-65.97
2050 RCP 6.0	-79.88	-80.30	-67.70	-68.68
2050 RCP 8.5	-77.39	-84.58	-72.32	-71.72
2070 RCP 2.6	-78.52	-81.16	-71.38	-58.97
2070 RCP 4.5	-72.22	-81.03	-70.93	-3.63
2070 RCP 6.0	-77.25	-81.03	-67.39	-71.92
2070 RCP 8.5	-64.11	-61.84	-36.08	-52.02

the optimal class with RCP 4.5 (2070) in compared to RCP 2.6, which will be present in the United Kingdom (Manchester, Birmingham, Bristol), Netherlands and Belgium areas toward the Northern Sea. Within India, the optimal class will occur exclusively in the southern region, mainly Maharashtra, whereas Rajasthan parts will be

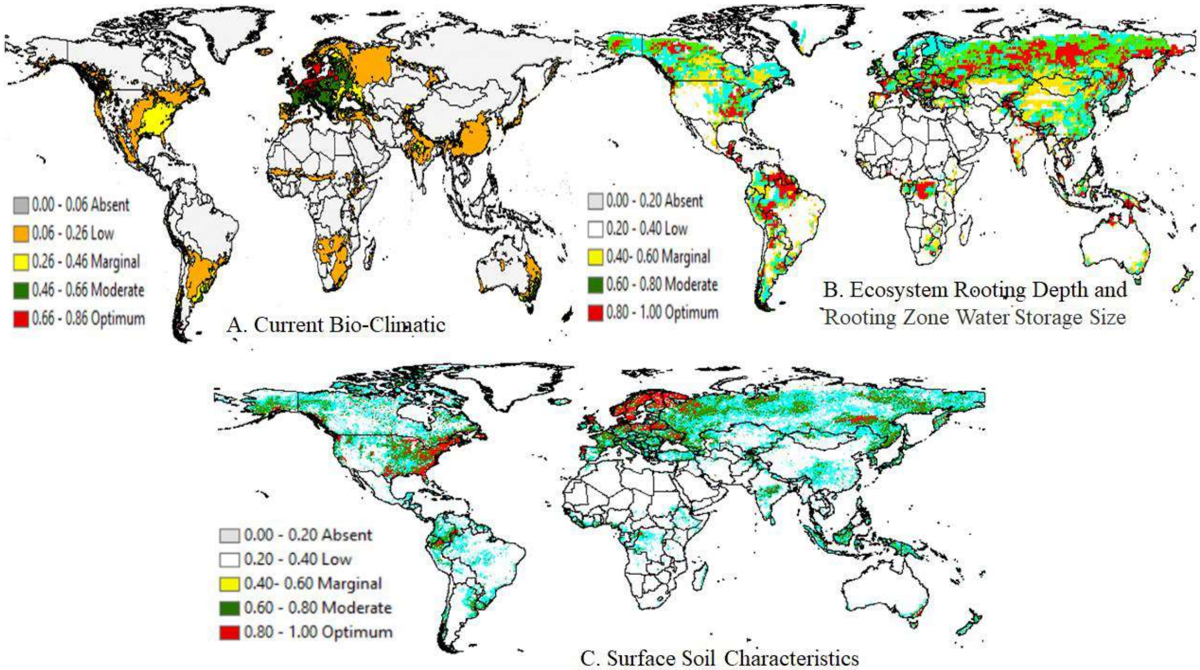

Fig. 6. Habitat suitability classification of *G. lucidum* with current bio-climate, surface soil, ecosystem rooting depth (95%), total plant-available water storage capacity of the rooting zone (TPAWSC RZ) predictors

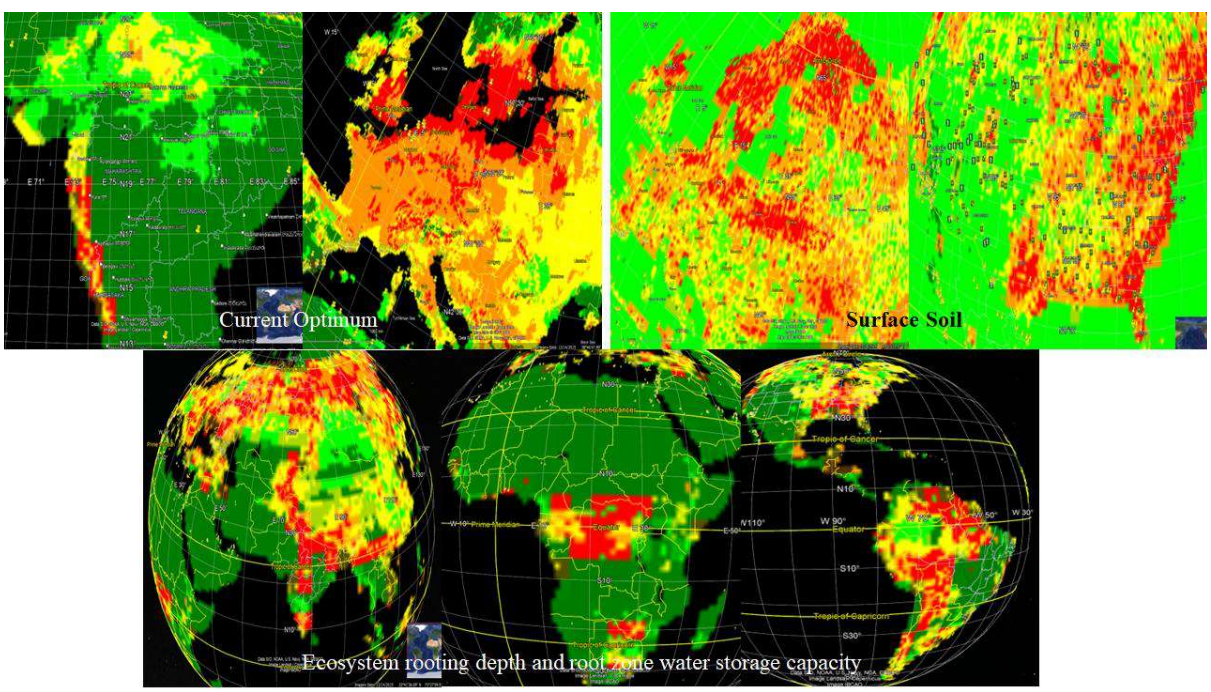

Fig. 7. Spatial distribution of *G. lucidum* captured with conversion of Maxent output to KML file showing impacts of current bio-climatic, surface soil properties and ecosystem rooting depth (95%) and total plant-available water storage capacity of the rooting zone predictors

unsuitable. With RCP 6.0 (2070), there will be a significant drop in optimum habitat in the European region, with only Denmark and a few places in the Netherlands and Belgium remaining. Except for a patch in Meghalaya, no such class will exist within the Indian subcontinent. Surprisingly, a larger area under the optimal category with RCP 8.5 (2070) than

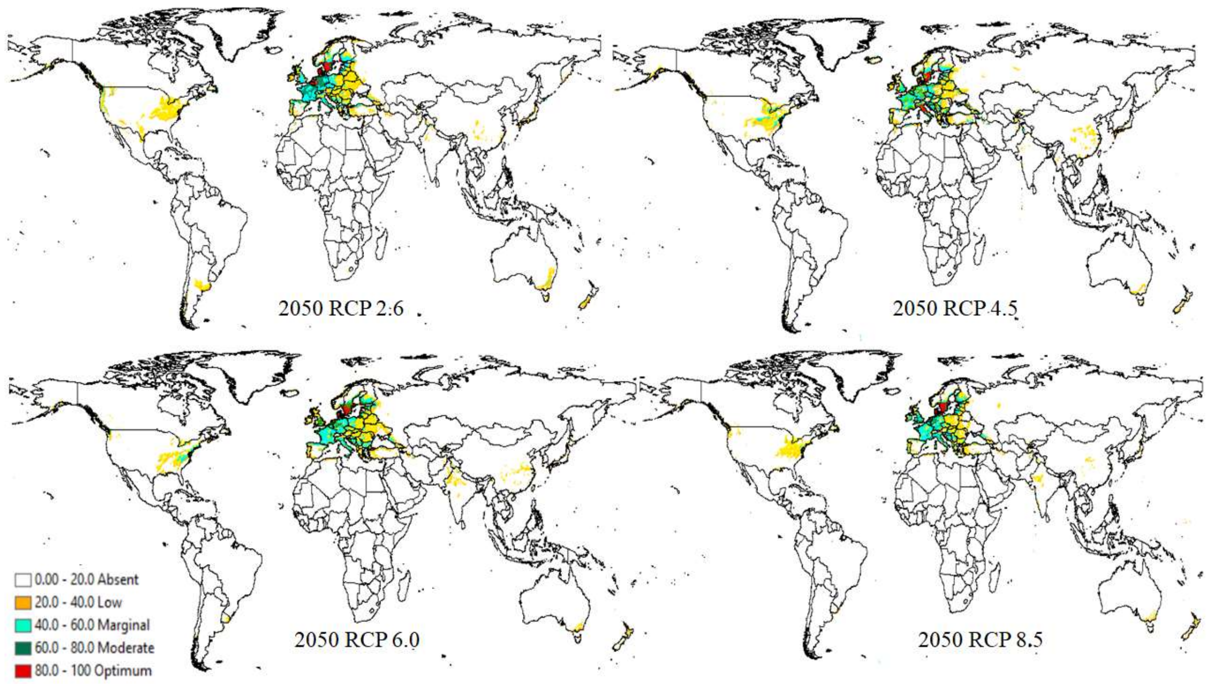

Fig. 8. Habitat suitability classification of *G. lucidum* with 2050 bio-climatic timeframes along with four RCPs viz. 2.6, 4.5, 6.0 and 8.5

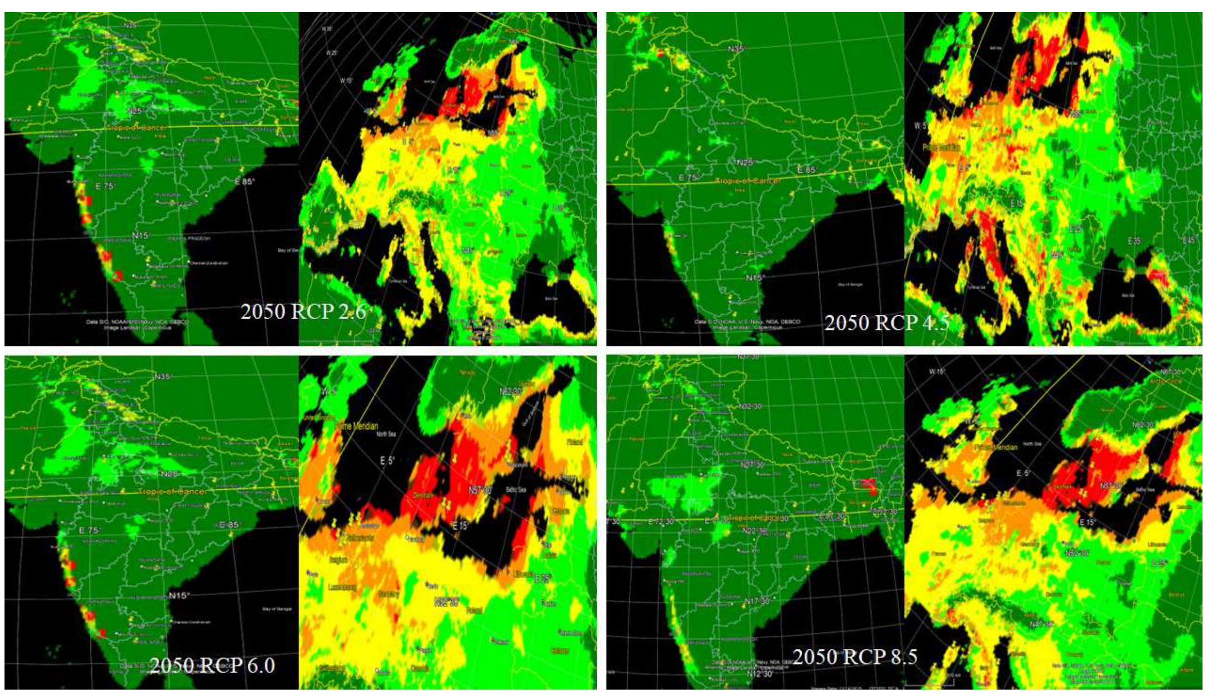

Fig. 9. Spatial distribution of *G. lucidum* captured with conversion of Maxent output to KML file showing impacts of 2050 bio-climatic variables along with four RCPs viz. 2.6, 4.5, 6.0 and 8.5

with the previous three RCPs. With this RCP, the southern coast of Maharashtra (Fig. 11) and, to a lesser extent, the eastern section of Meghalaya will be the focal point for this species. Afghanistan and Tajikistan will also have isolated portions of optimal class. Denmark and parts of the United Kingdom will be the most suitable European country for this fungus. While parts in the Netherlands, Belgium, and France will be classified as moderately suitable.

Plant fungi have a diverse geographical range and can thrive in tropical, subtropical, and temperate countries (Baino

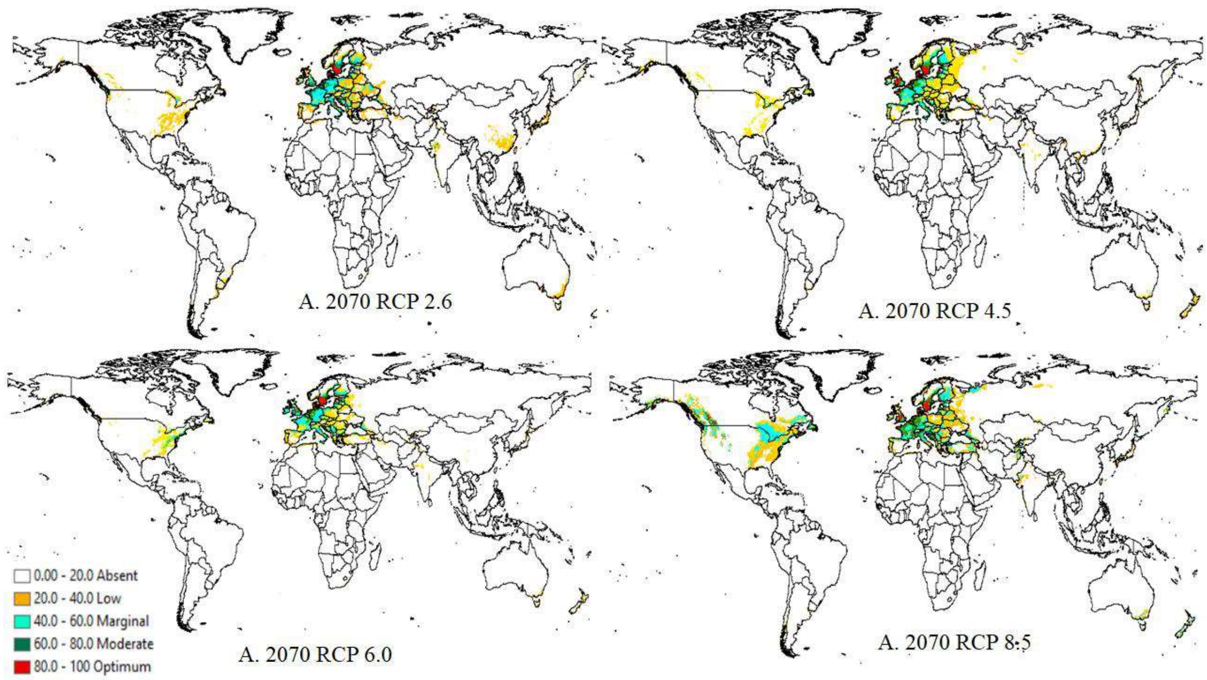

Fig. 10. Habitat suitability classification of *G. lucidum* 2070 bio-climatic timeframes along with four RCPs viz. 2.6, 4.5, 6.0 and 8.5

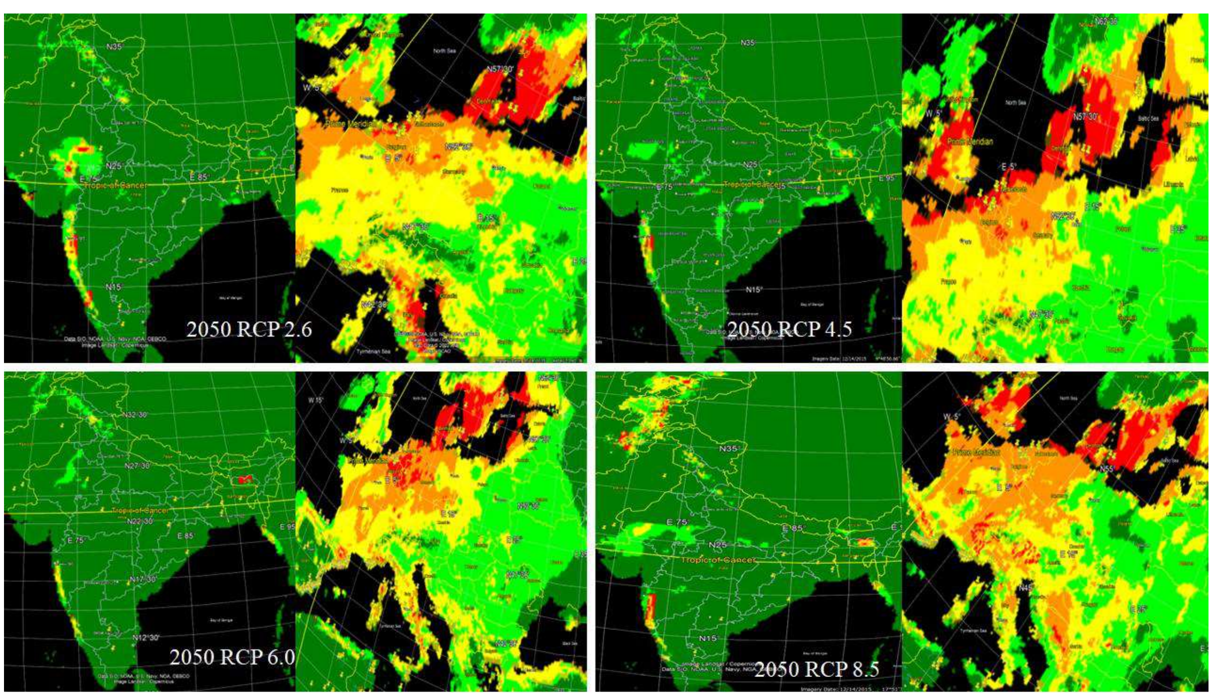

Fig. 11. Spatial distribution of *G. lucidum* captured with conversion of Maxent output to KML file showing impacts of 2070 bio-climatic variables along with four RCPs viz. 2.6, 4.5, 6.0 and 8.5

et al 2011, Cohen et al 2022). However, their eco-climatic niche modelling is comparatively lesser than the plants and animals that may be linked with requisition of deep ecological understanding for such analysis (Ireland and Kiritcos, 2019). Species distribution modelling (SDM) refers to statistical methodologies for determining a species' potential geographical spread and ecological needs (Mathur and Sundaramorthy et al. 2019). The mathematical output of SDM can be either an equation that ties the expected distribution of a species to a collection of environmental predictors or a response curve that describes how the predictors affect species distribution. SDM has been used in a variety of areas, including global change biology, biogeography, and conservation management (Li et al 2020). With presence-absence data SDM, involves two different sub-groups i.e., regression based and machine learning. Use of Maxent tool for plant fungi distribution assessment were carried out on *Polyporus umbellastus* (Liu et al 2015, Guo et al 2019), *Ganoderma lucidum* (Copot and Tanase 2017), *Suillus lakei* (Pietras et al 2018), *Tricholoma matsutake* (Guo et al 2017), *Fomitopsis pinicola*, *Porodaedalea laricis*, *Piptoporus betulinus* and *Trametes* suaveolens (Yuan et al 2019), *Calthrus archeri* (Birsan et al 2021), *Agaricus campestris, Calocybe gambos, Helvella crispa, Hypholoma lateritium, Mycena polygramma, Panaeolus foenisecii, Ramaria gracilis, Mycena polygramma* and *Mycena polygramma* (Stojek et al 2022), *Arcyria cinerea*, *Perichaena depressa* and *Hemitrichia serpula.*

A number of studies have demonstrated the utility of species distribution modelling (SDM)/or ecological niche modelling (ENM) for plant fungi in a variety of scientific inventories, including those concerned with estimating the likelihood of disease spread (Watt et al 2011, Yonow et al 2013), quantifying the value of assets (plant hosts) vulnerable to the pathogen (Watt et al 2009), and estimating costs (Chakraborty et al 1998, Ganley et al 2011, Yonow et al 2013). SDM could be an interdisciplinary plant fungal activity that has a favourable impact on global and regional policy responses. In recent years, the use of fungal SDM (F-SDM) has increased considerably in a variety of industries. F-SDMs were created for a variety of reasons, and according to Hao et al (2020) majority of them can be put into three broad categories (1) investigating environmental covariates of occurrence, (2) predicting occurrence in areas of interest, and (3) using fungi as a model organism to study methodological or ecological theories. In the current study, strong predictive model capabilities using bio-climatic time-frames and their related RCPs (AUC > 0.9) when compared to top-down variables such as soil parameters, ecosystem rooting depth, and root zone water holding capacity. As a result, it may conclude that bio-climatic variables will be the primary controlling elements affecting the habitat appropriateness of this fungus globally. Our findings also demonstrated a constant deterioration in *G. lucidium* optimum habitat with all forecasted RCPs and non-bioclimatic factors when compared to existing bio-climatic circumstances. Such findings are consistent with those of Vetrovsky et al (2019), demonstrated that several environmental conditions influence the global distribution of fungi, with climate being the most influential for the most common fungal species. The relative importance of mean driest quarter temperature (BC-9), precipitation seasonality, and fungal taxa distribution in decreasing order (BC-15), wettest quarter temperature (BC-8), coldest quarter precipitation (BC-19), mean diurnal range (BC-2), gross primary production, bulk density, and pH were all reported. Threshold limits for various secondary parameters were also identified, such as ecosystem rooting depth and soil organic carbon.

Plant fungal communities (dominated by Leotiomycetes, Agaricomycetes, Eurotiomycetes, and Sordariomycetes) are influenced by abiotic environmental variables such as soil (pH, nutrients, and particle size distribution) and climate (mean annual temperature and mean annual precipitation, Mathur, 2014b, Van Geel et al 2018; Wu et al 2018). Such bottom-up and top-down predictive variables also have temporal effects. For example, in two Japanese mountain habitats, temperature changes were identified to be the principal driver of variance in fungal community composition (Miyamoto et al 2015), but in Europe, AM fungal community composition was most substantially controlled by soil features (Van Geel et al 2018). Similarly, Vetrovsky et al (2019) used Random Forest analysis to assess the Variable Importance (VI) for the global distribution of 457 fungal species, and the VI were in the following order: wettest quarter mean temperature (BIO8)> coldest quarter precipitation (BIO 19)> diurnal temperature range (BIO2)> gross primary production> warmest quarter precipitation (BIO8).

In this study, it was observed that energy-related bio-climatic variables (BC-1 to BC-11, Table 3) had the greatest impact on the habitat types of this fungus, while precipitation-related variables (BC-12 to BC-19) have a lesser impact. Wang et al. (2018) used the same modelling approaches to anticipate future distribution *Pseudomonas syringae* pv. *actinidiae* (Psa) in China. Their research found that the highest April temperature (19%), the coldest quarter mean temperature (41%), and the lowest October temperature (10.8%) had the greatest influence on Psa spread. Furthermore, as temperature and moisture stress increase, *M. phaseolina* dry root rot and charcoal rot become more severe. Temperature increases (35-40°C) create pathogenic microsclerotia, exposing hosts to infection (Olaya and Abawi, 1996). High temperatures and dry conditions promote the growth of microsclerotia and increase the activity of hydrolytic enzymes within the microsclerotia, making infection simpler (Lalita and Ahir, 2020). Rising temperatures are expected to have an impact on the geographical distribution, virulence pattern, and presence of *M. phaseolina* in new areas in the near future (Arias et al 2011).

According to previous studies, *G. lucidum* mycelial growth is temperature-dependent, and this environmental factor essentially makes it easier for bacteria to grow on the fungus' fruiting body. By affecting the polysaccharide and other microelements in *G. lucidum* fruiting bodies through their enzymatic action, such bacteria support the growth of this fungus (Stajic et al 2002, Tanaka et al 2016). Jayasinghe et al (2008) have concluded that minimum and maximum cardinal temperatures for the mycelial growth and density of *G. lucidum* were 15 and 35° C, respectively. The best mycelial growth was reported between 30° C to 35° C. However, the current study suggested that with different RCPs and climatic time frames, habitat niche of this species will respond more toward the mean temperature of the coldest quarter (BC-11), and the maximum of habitat suitability with this predictor remained at temperatures -10 to +10° C for current climatic conditions (Fig. 5a) and -10 to 5°C at 2070 RCP 6.0 (Fig. 5h). Minimum temperature of coldest month (BC-6) was best suited for this species with a range of -10 to +10° C with RCP 4.5 of 2050 (Fig. 9c) and -10 to +8°C with RCP 4.5 (Fig. 5d) and 6.0 (Fig. 5e) of the same time-frame. While its habitat was altered by Isothermality at a range of 20 to 40% during 2070 RCP 4.5 (Fig. 5h) and 8.5 (Fig. 5i), its suitability fell dramatically after these threshold values. Thus, our study clearly demonstrates the decrease breadth of atmospheric temperature variabilities for this fungus.

Isothermality, which is a measure of how large day-to-night temperature oscillations are relative to the summer-to-winter (annual) oscillations, was found to be the most important factor for this species under the majority of climatic time-frame and greenhouse gas scenarios. An isothermal value of 100 indicates that the diurnal temperature range is comparable to the annual temperature range, whereas anything less than 100 (~30) indicates that the temperature variability is greater during an average month than it is throughout the entire year. In this study, lower isothermality values, indicating that seasonal variations may have a greater effect on the dispersal of this fungus than monthly temperature fluctuations.

It was also noticed that ecosystem rooting depth and rootzone water storage capabilities are pre-disposing factors for *G. lucidium* in the current environment. This is supported by the findings of Bhansali (2012), Ren et al (2020), and Fatmia et al (2022). Further lesions on the root surface promote fungal penetration into the host vascular system. However, no information about the rooting depth threshold that best supports this fungus's habitat was previously accessible. Based on the output of Response Curve Function (ROC), it can be depict the establishment mechanism of this fungus as it relates to optimal root depth and moisture availability. According to the analysis, 8 cm depth is the most optimum for this fungus growth, and anything beyond that reduces the fungus's habitat suitability dramatically. Furthermore, its well known that this fungus infection spreads directly from root to root, implying the importance of root lengths.

The spatial breadth of this fungus was also studied, and such field-based prediction can be utilised to estimate its wild region-specific production output, which can also be synchronised with its in-vitro propagation to fulfil industrial demands. Europe, for example, has the most potential for this species, followed by a few states in the United States. For improved assessments in Asian, African, and Australian locations, field-based exploration in remote/wild places is required. Despite the fact that many pharmacological clinical trials from China have been documented, as well as the pathogenic nature of this fungi on *Prosopis cineraria* tree and oil palm plantation from Indian regions, a lack of systematic surveys with proper geo-graphical coordinates impedes habitat-based niche modelling with advanced Machine Learning tools from such areas.

CONCLUSION

The machine learning Maxent modelling technique achieved outstanding model characteristics for *Ganoderma lucidum* fungus (AUC 0.90). Bioclimatic-energy variables (temperature) will more effectively manage its future global dispersion than water considerations (precipitation). In compared to the current optimum and moderate habitat areas, our research found a significant decline with examined predictors ranging from -73.74 to -87.56. This fungus, might assume, is constantly spreading over some European countries. However, within Asian regions, both optimum and moderate habitat suitability for this species will deteriorate, making wild collection for diverse pharmaceutical product manufacture more difficult. As a result, its availability in such locations will be heavily reliant on its *in-vitro* conditions (substratum) as well as the adjustment of micro-environmental variables identified in this work.

CONTRIBUTION

Senior author conceptualized the chapter theme and interpretation of output of various machine learning techniques. Co-Author prepared various types of language codes in python, Java and in R scripts and convert the various file format from ASCII to KML, Raster, dbf, CSV etc for software's like QGIS 3.10.0, Wallace, DIVA-GIS version 7.5, MaxEnt 3.4.1 software, SDM toolbox, Map Comparison Kit, ENMTools and Ntbox, SSDM R packages.

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Effect of FYM, Lime and Fertilizers on Forms of Soil Acidity and Relationship with Soil Properties in Acid Alfisol

Alisha Sharma, R.P. Sharma, N.K. Sankhyan Rameshwar Kumar[1] and Hari Mohan Meena[2]

Department of Soil Science,[1]Department of Organic Agriculture & Natural Farming, College of Agriculture
Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidhyalya, Palampur -176 062, India
[2]Department of Soil Science, Punjab Agricultural University, Ludhiana-141 004, India
E-mail: sharmaalisha832@gmail.com

Abstract: The field experiment was carried out on maize crop during *kharif* 2020 at CSKHPKV, Palampur to study the effect of fertilizers and amendments on forms of soil acidity and soil chemical properties in an acid Alfisol. The application of lime with 100% NPK and integrated use of FYM, lime and 100% NPK decrease the exchangeable acidity, total potential acidity, extractable acidity, pH dependent acidity, non-exchangeable acidity and total soil acidity. There was significant increase in the soil pH, CEC, organic carbon and available nutrients (N, P, K, Ca, Mg and S) under treatment 100% NPK + 10 t FYM/ha + lime (full dose through broadcasting) which was at par with 100% NPK + 10 t FYM/ha + lime (1/10th dose through furrow application). All forms of soil acidity observed significant negative correlation with available nutrients and soil properties except soil organic carbon which showed significantly positive correlation.

Keywords: Exchangeable acidity, Total potential acidity, Extractable acidity, pH dependent acidity, Non-exchangeable acidity, Total soil acidity

Maize (*Zea mays* L.) is cultivated widely throughout the world and has the highest production among all the cereals. It is considered as one of the fastest growing cereal crops in the world becoming the largest component of global coarse-grain trade and has a high production potential compared to any other cereal crop. In India, it ranks third in production after rice and wheat. However, the production is constrained due to declining soil health. Among other crop production constraints, soil acidity has been recognized as one of the important production problems across the globe. It is important to have the knowledge of the different forms of acidity, as this will help in management of acid soils. Soil acidity management is important for enhancing food security globally and regionally. In India, acid soils comprise about 92.79 m ha, out of which 62.14 m ha have pH range between 5.6-6.5 and in Himachal Pradesh, the extent of acid soil is 1.74 m ha (Maji et al 2012). The acidic soil condition is considered as major constraints in the maize cultivation. The fertility status of the acid soils is very poor and under strongly to moderately acidic soil conditions the plant growth and development is affected to a greater extent. The plant grown on such kind of problematic soils does not give profitable return rather it lowers down the yield considerably. The most practicable management practices are the use of lime and liming material to ameliorate the soil acidity. Lime application is recommended to increase the phyto-availability of essential nutrients and ameliorate the acidity-induced fertility constraints on such soils, thus enhancing the productivity as well as maintaining the soil health. In the earlier studies, the effect of combined use of FYM, lime and fertilizers on forms of acidity and soil-physico chemical was not evaluated. Therefore, the present study was undertaken in an acid Alfisol. Furthermore, the effect of natural farming in comparison with the state recommended dose of fertilizer was also observed.

MATERIAL AND METHODS

Location: The study was conducted at the Research farm of the department of Soil Science, CSKHPKV, Palampur, situated at 32^{0}7/N latitude and 76^{0}31/E longitude in Kangra district of Himachal Pradesh during kharif 2020.

Climate and weather: The climate of the study area is characterized by mild summers, severe winters and experiences occasional snowfall during winter. The annual rainfall of the area ranges from 2500 mm to 3000 mm. In general, a major part of the rainfall (about 75 per cent) is received during monsoon period from June to September. The soil of the experimental site was silt loam in texture and classified as *Typic Hapludalf* (Soil Survey Staff 1975).

Initial soil characteristics: At the initiation of the experiment, soil of the experimental field was acidic in reaction (pH 5.9), medium in organic carbon (8.34 g/kg), medium in available Nitrogen (N) (291 kg/ha) and medium in available P and K (11.16 and 228 kg/ha), respectively.

Treatments detail: The experiment comprised of eleven treatments which were replicated thrice and laid out in a randomized block design (Table 1). The maize crop was taken as a test crop and the variety used was *kanchan gold*. The recommended dose for maize crop is 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. The sources of N, P and K were urea, single super phosphate and murate of potash, respectively for all the treatments except T_1 (control) and T_{11} (natural farming). In treatments T_2 to T_{10} half dose of N and full dose of P and K was applied at the time of sowing of maize. The remaining half nitrogen was top dressed in two equal splits at knee high and pre-tasseling stage of maize. The FYM contained 45 per cent moisture and was incorporated on dry weight basis with average N, P and K nutrient content 0.96, 0.34 and 0.63 percent respectively and mixed well in the soil before sowing. The lime requirement was determined by SMP buffer method and marketable lime ($CaCO_3$) was applied as per treatments. In treatments T_5, T_7 and T_8, full dose of lime (4t/ha) was applied in the soil uniformly through broadcasting and thereafter mixed well in the soil, whereas in treatments T_6, T_9 and T_{10}, 1/10th dose of lime (0.4 t/ha) was applied in furrows. The treatment T_{11} was introduced to compare natural farming treatment with the already existing nutrient management practices recommended by the CSK Himachal Pradesh Krishi Vishvavidyalaya Palampur. Prior to sowing, *Ghanajeevamrita* was applied and incorporated into the plots at a rate of 250 kg/ha. Before sowing, seeds were treated with *Beejamrita* at a rate of 100 ml/kg seed. Application of *Jeevamrita* @ 500 l/ha was done at the time of sowing followed by spray of *Jeevamrita* at an interval of 21 days after dilution (1:10) with water.

Physical-chemical properties of soil: Soil samples collected from a depth of 0-0.15m after the harvest of maize (*Kharif* 2020) were used for determination of various chemical properties. The processed soil samples were analyzed for forms of soil acidity viz., exchangeable acidity, total potential acidity, pH dependent acidity, extractable acidity, non-exchangeable acidity and total soil acidity. Exchangeable acidity was determined by the method as outlined by McLean (1965). 0.5 N barium chloride ($BaCl_2$)-triethanolamine (pH – 8.0–8.2) reagent as extractant was used to determine the total potential acidity (Baruah and Barthakur 1998). The pH dependent acidity was calculated by subtracting the exchangeable acidity from total potential acidity. For extractable acidity, forty gram each soil samples were extracted with NH_4OAc solution (pH 4.8) and the values were determined by colorimetric method (Baurah and Barthakur 1998). Non-exchangeable acidity was determined by subtracting the value of exchangeable acidity from extractable acidity. Total soil acidity was estimated by extracting the soil with freshly prepared sodium acetate (NaOAc) solution (pH 8.2) described by Kappen (1934).

Statistical analysis: The data collected from the field study and laboratory was analyzed by online statistical analysis tools (OPSTAT) and technique of analysis of variance (ANOVA) for randomized block design was used for interpretation of results (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect of FYM, Lime and the Chemical Fertilizer on Soil Properties

Soil pH: There was significant increase in the soil reaction (pH), SOC and CEC with the combined application of organic and inorganic fertilizer. The highest soil pH was recorded

Table 1. Effect of FYM, lime and fertilizers on soil pH, SOC (g/kg) and CEC (c mol (p^+)/kg

Treatment	pH	SOC	CEC
T_1: Control	5.47	8.47	11.72
T_2: 100% NPK	5.60	8.83	12.23
T_3: 100% NPK + 5 t FYM/ha	5.68	9.64	12.50
T_4: 100% NPK + 10 t FYM/ha	5.73	9.73	13.00
T_5: 100% NPK + lime (Full dose through broadcasting)	5.78	9.61	13.50
T_6: 100% NPK + lime (1/10th dose through furrow application)	5.76	9.58	12.97
T_7: 100% NPK +5 t FYM/ha + lime (Full dose through broadcasting)	5.84	10.23	13.53
T_8: 100% NPK + 10 t FYM/ha + lime (Full dose through broadcasting)	5.91	10.60	14.20
T_9: 100% NPK + 5 t FYM/ha + lime (1/10th dose through furrow application)	5.77	10.20	13.00
T_{10}: 100% NPK + 10 t FYM/ha + lime (1/10th dose through furrow application)	5.75	10.55	13.47
T_{11}: Natural Farming (*Beejamrita*+ *Jeevamrita* +*mulch* +*Ghanajeevamrita* at 21 days interval)	5.66	8.71	11.94
CD (p=0.05)	0.17	0.49	0.83
Initial	5.49	8.34	11.68

under treatment T_8 and was at par with treatments T_5, T_6, T_7, T_9 and T_{10}. The application of FYM increased soil pH which could be due to decrease in exchangeable acidity which reduces the activity of Al^{+3} ions in the soil solution due to chelation by organic molecules (Rajneesh et al 2018).Lime has neutralizing effect which decreased the exchange acidity and exchangeable Al from the soil solution resulted in the increase in soil pH from its initial value (5.49) (Meena et al 2017)

SOC: The application of amendments along with the fertilizer significantly increase which ranged from 8.47 g/kg under control (T_1) to 10.60 g/kgi n T_8.Significant increase in the SOC was under the conjoint application of the fertilizer, FYM and lime in comparison with the control (T_1) and 100% NPK (T_2) and could be attributed to the direct addition of organic carbon through FYM and the addition of crop residues and root biomass (Tabassum et al 2010). Similarly, application of lime improved soil environment resulting in higher root biomass, crop residues and stubbles of the crop (Meena et al 2017).

CEC: The cation exchange capacity (CEC) varied from the lowest value of 11.72 c mol (p^+)/kg in control (T_1) to the highest of 14.20 c mol (p^+)/kg in T_8. The increase in CEC had been found in almost all the treatments as compared to initial value, wherein the initial status of 11.68 c mol (p^+)/kg was almost maintained. The 21.1 and 16.1 per cent increase in CEC was under treatment T_8 over control (T_1) and 100% NPK (T_2), respectively. The significant increase in the CEC value of the soil in the FYM treated plots might be due to increase in pH and the formation of the organic colloid (Hemalatha and Chellamuthu 2013). The substantial effect of lime on CEC may be attributed to the rise in pH and addition of Ca through lime (Dhiman et al 2019).

Available nitrogen: Application of FYM, lime either alone or in combination with recommended dose of fertilizer increased available nitrogen content in all the treatments compared with the initial status except control and 100% NPK. The initial available N content in the soil was 291 kg/ha, which declined to 283 kg/ha in the plots receiving zero fertilization i.e.; control the highest available nitrogen was recorded in treatment T_8 which was at par with the treatments T_7, T_9 and T_{10}. The lowest value of available nitrogen was in control which was significantly inferior to the rest of the treatments. FYM incorporation may attribute to the direct addition of nitrogen into the soil. Similar findings were recorded earlier by Hemalatha and Chellamuthu (2013) and Rajneesh et al (2018). Moreover, the lime improved the biological properties of soil which increases the mineralization of organic N (Verma et al 2012).

Available phosphorus: The available phosphorus content increase in the plots treated with FYM, lime and the inorganic fertilizers over the initial status (11.16 kg/ha), whereas non-significant increase in available phosphorus was recorded under control. Application of FYM and lime along with NPK increased the available phosphorus content by 15.0 kg/ha over its initial status. The substantial build-up of available phosphorus with the application of FYM which could be due to direct addition of P through FYM, solubilization of P by the organic acids released from the organic manure and decrease in P fixation in soil due to inactivation of iron, aluminum and hydroxyl-aluminum. Similar results were recorded by Urkurkar et al (2010) and Thakur et al (2011). The application of lime reduced P fixation because of decrease in exchangeable acidity and exchangeable Al and increased mineralization of organic P in the soil (Rajneesh et al 2018).

Available potassium: Available potassium increased in

Table 2. Effect of FYM, lime and fertilizer on available N, P, K, S (kg/ha) and exchangeable Ca and Mg (c mol ((p^+)/kg

Treatment	N	P	K	S	Ca	Mg
T_1	283	11.6	222	21.6	2.59	1.18
T_2	303	12.9	240	26.4	3.03	1.33
T_3	314	13.4	246	27.3	3.05	1.43
T_4	322	13.7	249	29.2	3.11	1.54
T_5	307	14.1	251	27.4	3.26	1.64
T_6	315	13.8	250	27.3	3.21	1.55
T_7	318	14.5	265	29.7	3.56	1.83
T_8	330	15.0	271	31.4	3.59	1.88
T_9	316	14.3	259	29.5	3.44	1.69
T_{10}	323	14.8	263	30.4	3.50	1.81
T_{11}	299	12.0	235	24.6	2.84	1.21
CD (p=0.05)	15.01	0.78	12.66	3.83	0.16	0.06
Initial	291	11.16	228	24.16	2.74	1.22

almost all the treatments except control (T_1) with its initial status of 228 kg/ha. The application T_8, however, increase the potassium status of the soil to 271 kg/ha. Compared with 100% NPK, treatments T_8 and T_{10} increased available potassium content by 12.9 and 9.6 per cent, respectively. Combining FYM with 100% NPK resulted in higher available potassium content, which might be attributed to the additional supply of potassium through FYM. Furthermore, the decomposition of FYM in soils resulted in the release of organic colloids, which increases CEC (Gouravet al2019). The use of lime in combination with inorganic fertilizers increased available potassium content of soil, which could be due to the exchangeable K being replaced by Ca produced by lime (Kumar et al 2014).

Available sulphur: The lowest value (21.6 kg/ha) of the available sulphur was under no fertilization plots which was at par with the plots treated with natural farming whereas the highest (31.4 kg/ha) was observed under treatment T_8. The higher values of available sulphur in FYM treated plots might be due to the direct supply of sulphur through FYM and decomposition of FYM released organic acids, leading to release of sulphur into the soil (Patel et al 2018). The lime resulted in increase in available sulphur content which may be due to improvement in biological activity of soil which led to the enhanced mineralization of organic matter and ultimately enhancing sulphur availability (Dhiman et al 2019).

Exchangeable calcium: Unfertilized control plot recorded the lowest value of exchangeable calcium whereas the highest was obtained under the integrated application of FYM, lime and chemical fertilizers (T_8). Sole application of lime in combination with 100% NPK also showed significant increase in exchangeable calcium content. The treatments T_4 and T_5 recorded increase of 20.0 and 25.9 per cent over control, respectively. The higher content of exchangeable Ca in FYM treated plots partly due to the direct supply of Ca from organic manure and partly due to the decomposition of organic matter which release the organic acid which solubilize Ca from the native pool in the soil (Anghileri 2009, Sanjivkumar 2014). Application of lime increased the exchangeable Ca that might be attributed to supply of Ca^{2+} ions from lime ($CaCO_3$) through dissociation (Chimdi et al 2012).

Exchangeable magnesium: Control plots resulted in lower value of 1.18 c mol (p^+)/kg of the exchangeable magnesium whereas the higher of1.88 c mol (p^+)/kg was under T_8 which was statistically at par with T_{10}. Application of T_8 increased the magnesium content by 59.3 per cent over control. Significantly higher value of exchangeable magnesium due to application of FYM could be attributed to release of Mg through manure (Babu et al 2007). However, lime increased exchangeable Mg content which could be due to the improvement in soil pH which increased the availability of Mg in soil (Rahman et al 2002).

Exchangeable acidity (EA): In comparison to the initial value (4.14 c mol (p^+)/kg), the highest decrease in the exchangeable acidity was observed under treatment T_8, whereas the control recorded the highest of the exchangeable acidity over the initial value. Integrated application of FYM, lime and fertilizer decrease the exchangeable acidity. The extent of decrease in exchangeable acidity under treatment T_8 was 40.5 per cent over control. Higher exchangeable acidity may be attributed to low pH in control treatment (T_1). The application of lime proved to be the most effective practice in reducing the exchangeable acidity due to its neutralizing effect on exchangeable Al^{+3}, H^+ and other hydrolysable acid producing ions or by increased replacement of Al by Ca on the exchange site and by the subsequent precipitation of Al as $Al(OH)_3$ (Bekele et al 2018). Application of FYM significantly decreases the exchangeable acidity which might be due to neutralizing reaction of FYM which leads to the release and subsequent hydrolysis of the Ca ions. The hydroxyl ions react with both exchangeable Al^{3+} and H^+ ions to form Al $(OH)_{3,}$ respectively (Rajneesh et al 2018).

Total potential acidity (TPA): Total potential acidity varied from a lowest value of 37.7 c mol (p^+)/ kg in the plots where the recommended dose of fertilizers was applied with lime (T_5) to a highest of 56.2 c mol (p^+)/kg in the plots that received FYM along with 100% NPK (T_4). Integrated application of chemical fertilizers along with FYM and lime decreased the total potential acidity significantly over T_4. Natural farming treated plots also showed a significant decrease in the total potential acidity in comparison with treatment T_3 and T_4. Organic matter contributes to total potential acidity through the presence of functional groups like-COOH and phenolic-OH. Similar results on total potential acidity have been reported by Dhananjaya and Ananthanarayana (2010) and Pati and Mukopadhyay (2010).

The reduction of total potential acidity with the addition of lime may attribute to neutralization of hydroxyl Al and Fe polymers by lime and also neutralization of the $Al^{3+,}$ H^+ and other hydrolysable acid producing ions or increases in replacement of Al by Ca in the exchange site and precipitation of Al as Al $(OH)_3$. These results corroborate the findings of Melese and Yli Halla (2016) and Rajneesh et al (2018)

pH dependent acidity (PDA): Organically amended plots (T_3 and T_4) registered significantly higher pH dependent acidity than rest of the treatments. The pH dependent acidity varied from 34.78 to 52.82 c mol (p^+)/kg under 100% NPK + lime (full dose through broadcasting) and 100% NPK + 10 t

FYM/ha, respectively. The pH dependent acidity comprises acidity emanating from the dissociation of protons from the functional groups viz., weakly acidic carboxyl groups (R–COOH) and phenolic hydroxyl groups (R–OH) on soil organic matter, as well as acidic protons on soil mineral edges (Dhanajaya and Ananthanarayana 2010). The higher value of pH dependent acidity in 100% NPK + FYM treatment can be explained on the basis of predominance of functional groups like carboxylic and phenolic on the organic matter. Lime incorporation resulted in lowering of pH dependent acidity. This could be due to the neutralization of hydroxyl- Al and Fe polymers (Rajneesh et al 2018).

Extractable acidity (Ext.): The variation in extractable acidity was from 4.22 c mol (p^+)/kg in 100% NPK + lime (full dose through broadcasting) (T_5) to 6.49 c mol (p^+)/kg in the plots receiving 100% NPK alone (T_2). Application of lime along with 100% NPK (T_5 and T_6) showed significantly lower value of extractable acidity than rest of the treatments. Similarly, optimal dose of fertilizers (100% NPK) in combination with FYM (T_8) resulted in significantly lower value of extractable acidity compared to the 100% NPK (T_2).The application of FYM had a moderating effect on extractable acidity, which could be attributed to the decrease in the activity of Al^{3+} ions in the soil solution due to chelation by organic molecules (Bharti and Sharma 2017). Decrease in extractable acidity due to lime application can be ascribed to neutralization of Al^{3+} ions with the addition of lime and increase in the base saturation (Goulding 2016).

Non-exchangeable acidity (NEA): The non-exchangeable acidity varied from a lowest value of 1.22 c mol (p^+)/kg under 100% NPK + lime (1/10th dose of lime through furrow application (T_6)

which was at par with treatment T_5 to a maximum value of 2.98 c mol (p^+)/kg under the sole application of10 t FYM/ha along with 100% NPK (T_4). The non-exchangeable acidity comprises of H covalently bound to colloids, and monomers and polymers of Al in soil and on expanded montmorillonite interlayers. Maximum value of non-exchangeable acidity may be because of low pH. Pati and Mukhopadhyay (2010) also reported similar results of non-exchangeable acidity with pH.

Total soil acidity (TSA): The total soil acidity varied from a minimum value of 37.50 c mol (p+)/kg in 100% NPK + lime (full dose through broadcasting to a maximum value of 67.2 c

Table 3. Effect of FYM, lime and fertilizer on forms of soil acidity

Treatment	EA	TPA	PDA	Ext.	NEA	TSA
T_1	4.25	48.5	44.20	6.14	1.89	47.8
T_2	3.77	51.5	47.76	6.49	2.72	52.5
T_3	3.58	54.1	50.56	6.16	2.58	58.5
T_4	3.39	56.2	52.82	6.37	2.98	67.2
T_5	2.91	37.7	34.78	4.22	1.31	37.5
T_6	3.21	40.3	37.04	4.43	1.22	42.5
T_7	2.71	41.0	38.32	4.52	1.81	49.2
T_8	2.53	42.9	40.40	4.37	1.84	44.2
T_9	3.25	44.3	41.08	4.85	1.60	49.2
T_{10}	3.13	46.1	42.93	5.08	1.94	48.3
T_{11}	3.97	49.1	45.1	5.88	1.91	53.3
CD (p=0.05)	0.48	7.88	7.67	0.56	0.60	6.95
Initial	4.14	49.2	42.4	6.22	2.08	44.62

Table 4. Relationship of different forms of acidity with soil properties

	N	P	K	Ca	Mg	S	pH	SOC	CEC
EA	-0.82**	-0.93**	-0.94**	-0.87**	-0.95**	-0.87**	-0.95**	0.87**	-0.98**
Ext. acidity	-0.45	-0.70	-0.70*	-0.51**	-0.75**	-0.51	-0.75**	0.63	-0.76**
PDA	-0.07	-0.39	-0.38	-0.17	-0.47	-0.17	-0.46	0.29	-0.48
TPA	-0.14	-0.45	-0.45	-0.24	-0.53	-0.24	-0.52	0.36	-0.54
TSA	0.09	-0.24	-0.21	-0.00	-0.28	-0.30	-0.26	0.14	-0.35
NEA	0.05	-0.27	-0.22	-0.01	-0.27	-0.30	-0.32	0.18	-0.30

mol (p^+)/ kg in 100% NPK + 10t FYM/ ha . The application of 100% NPK + 10t FYM/ ha and 100% NPK + 5t FYM/ ha recorded 28.0 and 11.4 per cent higher total soil acidity, respectively as compared to 100% NPK . Application of lime (T_5) led to significant reduction in total acidity in comparison to 100% NPK + 10t FYM/ ha and 100% NPK, the reduction being 44.2 and 28.6 per cent, respectively. The reduction in different forms of acidity due to application of lime results in the reduction in total acidity with the addition of lime is obvious (Subehia et al 2005).

Relationship of forms of soil acidity with soil chemical properties: The pH had a negative significant correlation with all forms of soil acidity viz; EA, TPA, PDA, Ext. acidity, NEA and TSA. Soil organic carbon had a significant positive correlation with all forms of acidity indicating the role of soil humus as a source of soil acidity by dissociating H^+at varying pH. The higher positive correlation was recorded by exchangeable acidity (r= 0.87) followed by extractable acidity (r= 0.63). All forms of acidity showed a significant negative correlation with the available nutrients and the cation exchange capacity of soil (Table 4).

CONCLUSION

All forms of acidity viz., EA, TPA, PDA, Ext. acidity, NEA and TSA decreased with the application of 100% NPK + 10 t FYM/ha + lime (full dose through broadcasting). Combined application of FYM, lime and recommended dose of fertilizer improved the soil properties (pH, SOC and CEC) and it also increases the availability of the nutrients (N, P, K, Ca, Mg and S) in the soil.

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Effect of Slow Release Coated Urea on Growth, Yield and Economics of Wheat (*Triticum aestivum*) under Subtropical Conditions of Jammu

Meenakshi Attri, Meenakshi Gupta, Sarabdeep Kour, N.P. Thakur and Rohit Sharma

Division of Agronomy, FOA, SKUAST-Jammu, Main Campus, Chatha-180 009, India
E-mail: meenakshiattri418@gmail.com

Abstract: An experiment was conducted under assured irrigated conditions of humid eco-region of Western Himalayas to study the effect of slow release coated urea on growth, yield and economics of wheat under subtropical conditions of Jammu. The experimental results revealed that application of 100% of Rec. N through ZnCU + Rec. P, K & Zn recorded significantly better growth measured in terms of plant height and dry matter production, yield attributing characters and grain and straw yield, during study and found at par with application of 85% of Rec. N through ZnCU+ Rec. P, K & Zn, 100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn, 85% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn and 100% of Rec. N through NCU + Rec. P, K & Zn. However with regard to economics application of 100 % of Rec. N through ZnCU+ Rec. P, K & Zn, recorded highest gross return, net returns and B:C ratio to the tune of ₹ 109005, ₹79018 and 2.64 respectively which was closely followed by 85 % of Rec. N through ZnCU + Rec. P ,K & Zn to the tune of ₹ 106341, ₹ 76580 and 2.57 respectively.

Keywords: Neem coated urea, Organic carbon, Slow release fertilizers, Zinc coated urea

Wheat (*Triticum aestivum* L.) is the main food for more than 35% of the world's population and globally, it is cultivated on an area of 225.62 million ha with production and productivity of 749.50 million tonnes and 3.32 tonnes/ha, respectively (Anonymous 2019). The countries leading in wheat cultivation are China, India, Thailand, Indonesia and U.S.A. In India, Uttar Pradesh stands first in production of wheat followed by Madhya Pradesh and Punjab Ramadas et al (2019). In J&K Union Territory (UT), wheat crop is grown on an area of about 290.99 thousand hectares with production and productivity of 0.58 million tonnes and 2.0 tonnes/ha, respectively (Anonymous 2019). The productivity of wheat in J&K is about 43.0 % less than the national productivity.

Wheat is a major source of plant protein with a protein content of about 13% in human food which is relatively high compared to other major cereals. The whole grain kernel of wheat, composed of bran (outer layer), wheat germ, and endosperm (innermost part), is an immense energy source. Wheat originated in Southwestern Asia, but today it is one of the top cereal crops grown in several countries for human consumption and is a rich source of nutrients for humans. The increase in wheat crop productivity mainly depends on the fertilizers used to supplement essential nutrients. Macronutrients like N, P and K in sufficient quantity throughout the growing season are essential for optimum growth. Both macro and micro nutrients are supplemented through synthetic fertilizers but the uptake and use efficiency of nutrients through commercial fertilizers is very less, causing soil and ground water pollution. Synthetic fertilizers have short-term benefits but cause long-term problems when applied in bulk as they leave residues which are toxic in nature and contributes heavy load to soil. Moreover, the increasing cost of fertilizers is also a burden for the farmer. Under these challenges, it would be difficult to produce enough food to feed the ever-increasing population, which is expected to cross 9 billion by 2050. To overcome the low nitrogen use-efficiency (NUE) various types of slow-release coated ureas, such as Neem coated urea (NCU), zinc coated urea (ZnCU), sulphur coated urea (SCU), polymer coated urea (PCU), water-soluble fertilizer, and biodegradable fertilizer materials have been developed. Moreover, from the year May, 2015 the entire production of urea has been converted as neem coated urea (NCU) to check its misuse in industries and benefits accrued in terms of increased production of crops (Swami 2015). Further, Bana et al (2021) concluded from his study that zinc coated urea (ZnCU) is a promising fertilizer for increasing rice production besides being an important low-cost and useful strategy for enhancing yield, nutrient us efficiency (NUE), biofortification and also in minimizing the Zn malnutrition related challenges in human diet in many developing economies. In this context, not much information is available on effect of slow release coated urea on growth, yield and economics of wheat under subtropical conditions of Jammu. Hence, this field study was undertaken to workout most suitable coated urea combinations for wheat crop under irrigated conditions of North-Western Himalayas of Jammu region.

MATERIAL AND METHODS

A field experiment was conducted during *rabi* (winter) seasons of 2017-18 at the Research Farm, Sher-e-Kashmir University of Agricultural Sciences Technology of Jammu, Chatha. The mean annual rainfall of study area is 1147 mm and more than 80% generally occurs during south-west *monsoon* season (July-September).

The soil of the experimental field was sandy clay loam in texture with slightly alkaline in reaction (7.42) and having 250.30 kg/ha of available N, 13.22 kg/ha available P, 120.40 kg/ha 1 N ammonium acetate exchangeable K and 0.38 % organic carbon. The DTPA extractable zinc was found below critical level (0.53 mg/kg). The treatments comprised of various doses of different types of coated urea *viz.* Prilled Urea, Neem coated urea (NCU), Zinc coated urea (ZnCU) and Neem+ Zinc coated urea (NCU + ZnCU). The experiment consisted of eleven treatment combinations *viz*. T_1: No N + Rec. P, K & Zn, T_2: 100% Rec. N through Urea + Rec. P, K & Zn, T_3: 70% Rec. N through NCU + Rec. P, K & Zn, T_4: 85% of Rec. N through NCU + Rec. P, K & Zn, T_5: 100% of Rec. N through NCU + Rec. P, K & Zn, T_6: 70% of Rec. N through ZnCU + Rec. P, K & Zn, T_7: 85% of Rec. N through ZnCU + Rec. P, K & Zn, T_8: 100% of Rec. N through ZnCU + Rec. P, K & Zn, T_9: 70% of Rec. N through NCU + ZnCU + Rec. P, K & Zn, T_{10}: 85% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn, T_{11}: 100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn, arranged in randomized block design with three replications.

Wheat crop variety HD-3086 was sown on 27th November of crop experimentation at 20 cm row spacing and seed rate of 100 kg/ha. For N application prilled urea, NCU, ZnCU and NCU + ZnCU were used as sources. The recommended dose of $N:P_2O_5:K_2O:ZnSO_4$ for wheat crop is 100:50:25:20 kg/ha. Fertilizer application was done based on initial soil test values i.e. soil was low in N but medium in P and K. Accordingly, N dose was increased by 25% *i.e.* 125 kg/ha of N was applied as recommended dose Whereas, for P and K fertilizer application, single super phosphate and muriate of potash were used as source of nutrients. Full dose of P_2O_5 and K_2O along with half of N were applied as basal and remaining N was applied in two splits at CRI stage and pre booting stage as per the treatments. Weed control was done by applying Pendimethalin @1.5 kg/ha, two days after sowing. Intercultural operations and plant protection measures were adopted as per the recommended package of practices. The crop was irrigated as and when necessary to maintain the optimum moisture condition of the field. The crop was harvested and threshed manually in each plot and necessary observations were recorded from individual plots. Data on yield attributes, grain and straw yield of wheat was recorded as per the standard procedures. The experimental results were analyzed statistically using analysis of variance (ANOVA) appropriate for randomized block design and the treatment means were compared using least significant difference (LSD) test at 5 % level of significance (Cochran and Cox 1957).

RESULTS AND DISCUSSION

Growth of wheat: Plant height is a growth parameter and indicates the influence of various nutrients on plant metabolism. Plant height recorded at 60 days after sowing and at harvest is presented in (Table 1). A significant effect of different types of coated urea was observed on plant height of wheat 60 DAS and at harvest stage. At 30 DAS significantly more plant height was reported in T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) but remained at par with T_{11} (100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_5 (100% of Rec. N through NCU + Rec. P, K & Zn). At harvest, application of different treatments proved instrumental in increasing plant height, and maximum plant height (114.61 cm) was recorded in T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) than other treatments, but it remained at par with treatment T_{11} (100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn), T_7 (85% of Rec. N through ZnCU + Rec. P, K & Zn) and T_5 (100% of Rec. N through NCU + Rec. P, K & Zn) with the values 112.75 cm, 111.72 cm and 110.98 cm, respectively. However, lowest plant height (79.63 cm) was recorded in treatment T_1 (No N + Rec. P, K & Zn. The significant increase in the plant height of wheat by use of coated urea might be explained on the basis that neem and zinc coated urea played a major role in the shoot and root elongation due to activation of auxin hormone in the wheat crop. Shivay and Prasad (2012) and Gupta et al (2022) also found that plant height was more enhanced when coated urea was combined with micronutrients it can either provide nutrients for the plant or aid in the transport or absorption of available nutrients resulting in better crop growth.

Dry matter accumulation of wheat crop (Table 1) showed significant variation with the application of different doses and types of coated fertilizer. Analysis of data pertaining to dry matter accumulation of wheat crop showed that significant increase in dry matter accumulation was observed in all the treatments at 60 DAS and at harvest stage. At 60 DAS, maximum dry matter accumulated under the treatment 100% of Rec. N through ZnCU + Rec. P, K & Zn followed by 100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn. At harvest, among the treatments, T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) resulted in significantly higher dry matter accumulation (246.06 g m/row length) which was statistically at par with T_{11} (100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn), T_5 (100% of Rec. N through NCU + Rec. P, K & Zn), T_7 (85% of Rec. N through ZnCU + Rec. P, K & Zn) and T_{10} (85% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) with the values 244.2, 243.6, 240.50 and 240.47 g/m row length respectively. Lowest dry matter accumulation (174.0 g/m row length) was observed in control (No N + Rec. P, K & Zn) at harvest.

This may be due to the balanced application of Zn along with NPK fertilizer, as zinc is involved in a number of physiological processes of plant growth and metabolism. Zinc Coated urea provides all the essential growth promoting elements for shoot growth, root development, photosynthesis, cell division and cell enlargement due to which meristmatic activity increased and resulted in improved overall growth of the plant. These findings corroborate to the findings of Shivay and Prasad (2012) and Kumar et al (2016).

Leaf area index is an important plant growth index which determines the capacity of plants to trap solar energy for photosynthesis and crop yield (Table 1). A significant effect of coated urea was observed on leaf area index of wheat crop. Application of different treatments combinations proved instrumental in increasing LAI of wheat. Among the different treatments, maximum LAI (4.49) was recorded in T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) at 60 DAS which was at par with T_{11} (100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_5 (100% of Rec. N through NCU + Rec. P, K & Zn) with the values of 3.67 of T_{11} and 3.62 of T_5. At harvest, maximum LAI (2.93) was recorded in T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) which was at par with T_{11} (100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_5 (100% of Rec. N through NCU + Rec. P, K & Zn) with the values of 2.88 of T_{11} and 2.87 of T_5. Lowest LAI was recorded in treatment T_1 (No N + Rec. P, K & Zn) at all the growth stages. The significant increase in the leaf area index of wheat as influenced by coated urea might be explained on the basis that the slow release coated urea led to the regulated release rate of N, synchronizing with the requirement of growing plants and efficient assimilation.

Crop growth rate: Data with respect of periodic and final crop growth rate (CGR) indicated that use of coated urea affect significantly CGR at all the stages of growth. The crop growth rate increased with the advancement of the crop age up to 120 DAS except control as shown in Figure 1.

A perusal of data depicted that initial CGR at 30-60, 60-90 and 90-120 DAS showed significant difference. Among the applied treatments, it was seen that significantly highest CGR at 90-120 DAS was recorded in T_8 (100 % of Rec. N through ZnCU + Rec. P, K & Zn) than other treatments in comparison. However it was at par with T_{11} (100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_5 (100 % of Rec. N through NCU + Rec. P, K & Zn) with respective values 14.75 and 14.80 (g/m^2/day.) However CGR at 120-harvest showed non significant difference. Treatment T_1 (No N + Rec. P, K & Zn) recorded lowest value of crop growth rate at all the growth stages

Table 1. Effect of slow release coated urea on plant height, dry matter accumulation and leaf area index of wheat

Treatments		Plant height (cm)		Dry matter accumulation ($g\ m^{-1}$ row length)		Leaf area index	
		60 DAS	At harvest	60 DAS	At harvest	60 DAS	At harvest
T_1	No N + Rec. P, K & Zn	34.21	79.63	33.46	174.00	2.98	2.07
T_2	100 % Rec. N through Urea + Rec. P, K &Zn	38.26	95.72	45.59	237.90	3.60	2.54
T_3	70 % Rec. N through NCU + Rec. P, K & Zn	34.79	90.02	39.45	220.80	3.37	2.47
T_4	85 % of Rec. N through NCU + Rec. P, K & Zn	40.33	99.81	44.19	235.34	3.55	2.68
T_5	100 % of Rec. N through NCU + Rec. P ,K & Zn	43.49	110.98	45.76	243.60	3.64	2.87
T_6	70 % of Rec. N through ZnCU + Rec. P, K & Zn	35.03	91.87	41.06	223.32	3.40	2.49
T_7	85 % of Rec. N through ZnCU + Rec. P ,K & Zn	41.24	111.72	46.55	240.50	3.62	2.72
T_8	100 % of Rec. N through ZnCU + Rec. P, K & Zn	46.67	114.61	50.22	246.06	3.70	2.93
T_9	70 % of Rec. N through NCU + ZnCU+ Rec. P ,K & Zn	34.97	91.65	39.72	222.66	3.37	2.48
T_{10}	85 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	40.46	99.96	44.86	240.47	3.55	2.75
T_{11}	100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	43.53	112.75	46.22	244.20	3.67	2.88
SEm±		1.15	1.29	1.52	1.89	0.02	0.03
CD (P=0.05)		3.22	3.84	4.51	5.61	0.06	0.08

Relative growth rate: The mean relative growth rate recorded a fluctuating trend from 30-120 DAS and declined with the advancement of crop age. A perusal of data depicted in Figure 2 revealed that coated fertilizers failed to show any significant effect with respect to relative growth rate of wheat crop at all the stages of growth.

Yield attributes and yield: The use of different types and doses of coated urea had significant effect on yield attributing characters as well as grain and straw yield of wheat. The data depicted in Table 2 that Treatment T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) though at par with treatment T_5(100% of Rec. N through NCU + Rec. P, K & Zn), T_7(85% of Rec. N through ZnCU + Rec. P, K & Zn), T_{10}(85% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_{11}(100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) recorded in significant increase in number of tillers per meter row length, grains per spike and 1000-grain weight and yield of wheat. This may be due to optimal supply of nutrients to the wheat crop upon use of recommended dose of fertilizers, thereby resulting in better growth and development of the crop. Bana et al (2021) and Gupta et al (2022) reported that number of tillers per metre row length also showed significant increase due to use of coated fertilizers which may have increased Zn membrane integrity, auxin-synthesis, chlorophyll synthesis and metabolism of N thereby enhancing photosynthesis, translocation of photosynthates to grain and thus increased crop yield in these treatments.

Similiar trend was observed in grain and straw yield (Table 3.) i.e. significantly higher grain and straw yield was recorded in treatment T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) which remained statistically at par with T_{11}

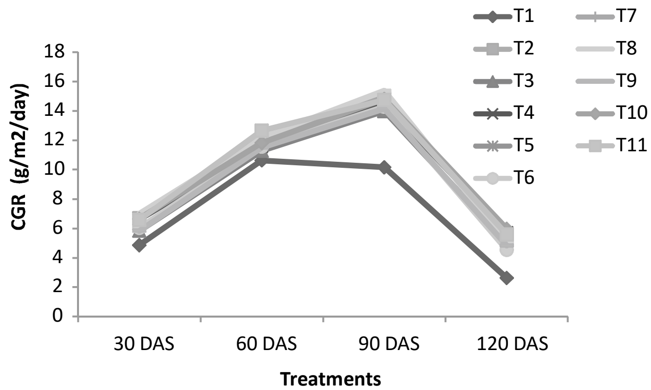

Fig. 1. Effect of coated urea on crop growth rate (g/m^2/day) of wheat

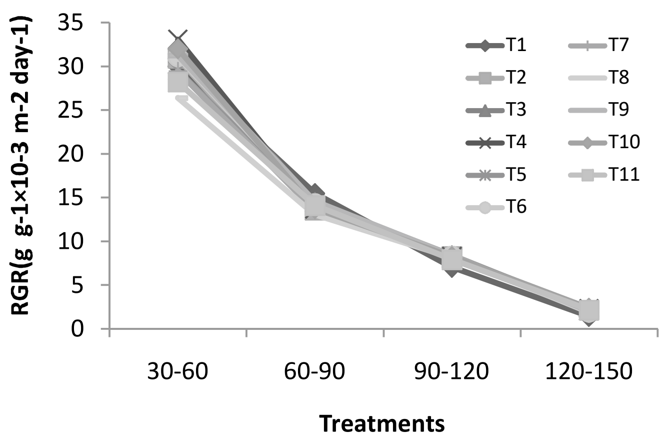

Fig. 2. Effect of coated urea on relative growth rate (g g^{-1}×10^{-3} m-^{2}day-^{1}) of wheat

Table 2. Effect of slow release coated urea on yield attributes of wheat

Treatments		Tillers m^{-1} row length	No. of spike m^{-2}	Grains spike^{-1}	1000 grain weight (g)	Length of the ear (cm)
T_1	No N + Rec. P, K & Zn	50.80	254.04	30.20	35.53	9.33
T_2	100 % Rec. N through Urea + Rec. P, K &Zn	58.74	293.71	35.00	40.39	13.28
T_3	70 % Rec. N through NCU + Rec. P, K & Zn	55.26	278.84	31.01	36.43	10.83
T_4	85 % of Rec. N through NCU + Rec. P, K & Zn	58.54	292.71	34.55	38.22	12.09
T_5	100 % of Rec. N through NCU + Rec. P ,K & Zn	61.67	308.37	36.61	40.92	13.35
T_6	70 % of Rec. N through ZnCU + Rec. P, K & Zn	56.04	281.24	32.61	36.64	11.06
T_7	85 % of Rec. N through ZnCU + Rec. P ,K & Zn	60.08	300.41	36.99	38.93	12.30
T_8	100 % of Rec. N through ZnCU + Rec. P, K & Zn	62.47	312.37	39.05	42.53	14.02
T_9	70 % of Rec. N through NCU + ZnCU+ Rec. P ,K & Zn	55.88	280.76	31.15	36.55	11.00
T_{10}	85 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	59.99	299.99	34.81	38.90	12.28
T_{11}	100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	62.14	310.70	37.33	41.05	13.43
SEm±		1.07	4.13	1.11	0.72	0.32
CD (P=0.05)		3.19	12.40	3.30	2.16	0.96

Table 3. Effect of slow release coated urea on yield and economics of wheat

Treatments		Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Cost of cultivation	Gross returns ($Rs.\ ha^{-1}$)	Net returns ($Rs.\ ha^{-1}$)	B:C ratio
T_1	No N + Rec. P, K & Zn	2.81	5.98	71826	28168.0	43657.7	1.55
T_2	100 % Rec. N through Urea + Rec. P, K &Zn	4.25	7.41	101932	29700.5	72231.1	2.43
T_3	70 % Rec. N through NCU + Rec. P, K & Zn	3.90	6.94	96396	29297.8	67097.8	2.29
T_4	85 % of Rec. N through NCU + Rec. P, K & Zn	4.29	7.47	102890	29537.0	73353.0	2.48
T_5	100 % of Rec. N through NCU + Rec. P ,K & Zn	4.39	7.53	104894	29773.8	75120.2	2.52
T_6	70 % of Rec. N through ZnCU + Rec. P, K & Zn	3.98	7.00	98412	29527.5	68884.8	2.33
T_7	85 % of Rec. N through ZnCU + Rec. P ,K & Zn	4.44	7.68	106341	29760.5	76580.1	2.57
T_8	100 % of Rec. N through ZnCU + Rec. P, K & Zn	4.55	7.88	109005	29986.5	79018.1	2.64
T_9	70 % of Rec. N through NCU + ZnCU+ Rec. P ,K & Zn	3.96	6.98	98053	29503.2	68549.7	2.32
T_{10}	85 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	4.32	7.48	103495	29745.2	73709.8	2.48
T_{11}	100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn	4.49	7.71	107266	29977.2	77288.8	2.57
SEm±		0.88	1.34				
CD (P=0.05)		2.62	4.0				

(100% of Rec. N through NCU + ZnCU+ Rec. P, K & Zn), T_7 (85% of Rec. N through ZnCU+ Rec. P, K & Zn), T_5 (100% of Rec. N through NCU + Rec. P, K & Zn) and T_{10} (85% of Rec. N through NCU + ZnCU + Rec. P, K & Zn), whereas treatment T_1 (No N + Rec. P, K & Zn) recorded significantly lowest grain and straw yield. The increase in grain and straw yield might be due to adequate quantities and balanced proportion of plant nutrients supplied to the crop during the critical growth period causing favourable increase in yield attributing characters. This in turn led to better nutrient absorption by plant cells resulting in optimal growth of plant parts and metabolic processes such as photosynthesis which ultimately led to higher accumulation of photosynthates and their translocation to the economic parts of the plant. These findings corroborate to the findings of Shivay et al (2015) and Bana et al (2021).

Economics: The economic feasibility and usefulness of a treatment can be effectively adjudged in terms of B: C ratio, gross returns and net returns (Table 3). The treatment T_8 (100% of Rec. N through ZnCU + Rec. P, K & Zn) fetched more gross returns (109005 Rs./ha) as well as net returns (79018 Rs./ha) followed by treatment T_{11} (100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_7 (85% of Rec. N through ZnCU + Rec. P, K & Zn). Treatment T_1 (No N + Rec. P, K & Zn) fetched lowest gross returns (71826 Rs./ha) and net returns (43658 Rs./ha) which was ultimately due to the difference in grain and straw yield of wheat crop and cost of fertilizers incurred at different treatments. Similarly, higher B:C ratio of 2.64 were observed in treatment T_8 (100 % of Rec. N through ZnCU + Rec. P, K & Zn), followed by B:C ratio of 2.57 in the treatments T_{11} (100 % of Rec. N through NCU + ZnCU+ Rec. P, K & Zn) and T_7 (85% of Rec. N through ZnCU + Rec. P, K & Zn). The lowest B:C ratio was observed in treatment T_1 (No N + Rec. P, K & Zn). Similar findings were also observed by Kumari and Chaudhary (2018) and also Gupta et al (2022). Higher net returns was ultimately due to the difference in grain and straw yield of wheat crop and cost of fertilizers incurred at different treatments.

CONCLUSIONS

Among the different doses of coated urea, application of 100% of Rec. N through ZnCU + Rec. P, K & Zn recorded significantly higher grain and straw yield, which was however, statistically at par with 85% of Rec. N through ZnCU+ Rec. P, K & Zn. Similarly, gross return, net returns and B:C ratio were also recorded highest under application of 100 % of Rec. N through ZnCU+ Rec. P, K & Zn than other treatments in comparison.

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Performance of Wheat (*Triticum aestivum* L.) Varieties under Cold Stress Condition

Radha Upadhyay, Girish Chandra[1]*, Lokesh Gambhir[2] and Pankaj Kumar[3]

Department of Agronomy, [1]Department of Seed Science and Technology
School of Agricultural Sciences, SGRR University, Dehradun-248 001, India
[2]Department of Biotechnology, School of Basic and Applied Sciences
SGRR University, Dehradun-248 001, India
[3]Department of crop improvement, College of Forestry, Ranichauri-249 199, India
**E-mail: girishctiwari24@gmail.com*

***Abstract*:** The present investigation was conducted during the *Rabi* season of 2020-2021 at Agricultural Research Farm of SGRR University, Dehradun, India to study the performance of wheat varieties under cold stress condition. The experiment was laid out in factorial randomize block design with three replications. The treatments comprises five sowing dates *viz*. 5th November, 15th November, 25th November, 5 December and 15th December and two varieties *i.e.* Unnat PBW 343 and PBW 502. The variety Unnat PBW 343 performs better than variety PBW 502 in yield and yield contributing traits. The plant height (101.44 cm), number of tiller per plant (10.71), spike length (14.49 cm), number of grains per spike (74.30), test weight (39.72 g) and grain yield (43.34 q/ha) was recorded maximum with 15th November sowing. The interaction of variety Unnat PBW 343 and 15th November sowing gave maximum yield (42.67 q/ha) as compared to all other treatments combinations. It can be concluded that under prevalent climatic conditions of Dehradun region, the variety Unnat PBW 343 and 15th November sowing time is best for higher yield of wheat crop as compared to all other treatments.

***Keywords*:** Sowing date, Wheat, Varieties and yield

Changing climatic conditions in recent decades is creating a major hurdle in enhancement the productivity of crops. With the changing environmental conditions, it is difficult to get higher yield and productivity by using traditional practices. It means traditional practices need to changed or modified (Xiao et al 2017). Knowledge of ideal sowing time of wheat crop as per climatic conditions is a key factor to get higher yield output without any extra economic inputs (Ali et al 2021). Wheat is playing an outstanding role in feeding the hungry people of the world and an important crop for global food security. In India, wheat is the second most important cereal crop next only to rice. It is a prime crop of the green revolution and post green revolution era. Among various factors responsible to influence the yield of wheat crop, sowing time and varietal selection are of primary importance. The environment under which crop is grown creates a tremendous impact on growth, development and yielding ability of wheat crop. It is a prime factor which affects the physiology and phenology of crop (Ahmed and Ali 2015). Wheat is sown in winter and it has its own definite requirements for temperature and light for emergence, growth and flowering. Too early sowing produces weak plants with poor root system and irregular germination. It is mainly because of the higher temperature than the required optimum temperature. Late planting results in poor tillering and slow crop growth because of low temperature. Late planting results short duration crop that may escape from high temperature at grain filling stage (Akter and Islam 2017).

Improper selection of varieties also affects crop yield because they vary with their genetic potential and adaptable environment. Thus there is scope for increasing crop yield by using climate resilient varieties (Hussain et al 2012). Many high yielding varieties have been developed and recommended for general cultivation in the past. These varieties are losing yield potential due to changes in various edaphic and environment conditions. Therefore, continuous selection of high yielding genotypes that have evolved various mechanism to cope up with heat stress which are rolling, shedding and thickening of leaves, reduction in leaf size, short duration of growth period and transpiration (Wahid et al 2007). Wheat yield can be increased 10-80 % through proper selection of sowing time and by using suitable cultivars (Conventry et al 2011). Hence, selection of optimum time of sowing and suitable variety is very essential to increase yield per hectare. Thus, the present investigation was conducted to determine the effect of date of sowing and varieties on growth and yield of wheat at the Doon valley of Uttarakhand.

MATERIAL AND METHODS

The present investigation was carried out during the rabi season of 2020-2021 at SGRR University, Dehradun, Uttarakhand. The experimental site was situated at 30.316ºN latitude and 78.032ºE longitude with an average altitude of 450 m above the sea level under subtropical and humid region of Dehradun. The soil of the experimental station was sandy loam to clay in texture containing a pH 6.5. The treatments comprise of different sowing dates and two wheat varieties which replicated thrice in two-factorial randomize block design. The sowing of two wheat varieties *i.e.* Unnat PBW 343 (V_1) and PBW 502 (V_2) were done on 5th November (T_1), 15th November (T_2), 25th November (T_3), 5th December (T_4) and 15th December (T_5). All other agronomic practices like weeding and irrigation etc. were used as per crop's requirements. The crop growth and yield parameters were recorded in five randomly selected plants from each plot. The average value of five selected plants were calculated for each parameter in each treatment and used for statistical analysis. The experimental data were statistically analysed by using SPSS.

RESULTS AND DISCUSSION

Plant Height (cm)

Effect of varieties: Plant height is mainly controlled by its genetic makeup and also affected by environmental conditions during the production. Plant height shows non-significant variation between varieties after 60 days after sowing, while it was significant at the time of maturity. The plant height at maturity was higher in variety Unnat PBW 343 (V_1) (100.10 cm) as compare to variety PBW 502 (V_2) (97.32 cm). This significant variation might be due to the genetic constitution of varieties in prevailing environmental condition. These results are also in agreement with the finding of Mattas et al (2011).

Effect of date of sowing: The plant height was significantly affected by different dates of sowing at 60 days after sowing (DAS) and maturity. The maximum pant height was 51.10 cm at 60 days after sowing and 101.44 cm at maturity with 15th November sowing. It might be due to suitable conditions for sowing of wheat crop as compared to other dates of sowing. The plant height was decreased gradually when sowing done after 15th November. This might be due to non-availability of suitable environmental conditions for enhancing effect of vegetative growth by cell division and cell elongation. Minimum plant height at 60 days after sowing (46.88 cm) and maturity (96.73 cm) were with 15th December sowing. These findings are in close conformity with the finding of Pathania et al (2018).

Interaction effect (V×T): At 60 days after sowing, the maximum plant height was recorded (51.12 cm) with treatment combination Unnat PBW 343 and 15th November sowing (V_1T_2), which was statistically at par to the treatment combination PBW 502 and 15th November sowing date *i.e.* 51.09 cm. It was 8.45 % higher than the minimum plant height (46.80 cm) with treatment combination PBW 502 and 15th November date of sowing. At maturity the highest plant height was recorded with (103.38 cm) with treatment combination Unnat PBW 343 and 15th November sowing, which was statistically at par to treatment interaction Unnat PBW 343 and 25th November date of sowing. Minimum plant height 94.82 cm was with treatment interaction V_2T_5. These findings are also in agreement with the findings of Adam and Jahan (2019).

Number of Leaves per Plant

Effect of varieties: A non-significant variation was recorded in number of leaves per plant at 60 days after sowing (DAS) but it was significant at maturity. At maturity Unnat PBW 343 gives 22.25 per cent higher number of leaves per plant than variety PBW 502. Bachho et al (2017) found significant effects of varieties on number of leaves at all growth stages.

Effect of date of sowing: Number of leaves per plant was varies significantly at 60 days after sowing and maturity with different dates of sowing. Maximum number of leaves per plant was in 15th November sowing *i.e*. 63.87 at 60 days after sowing and 4.10 at maturity. The minimum number of leaves per plant was in 15th December sowing date at both the growth stages. It might be because of the different environmental conditions faced by crop plants. It might also be due to higher plant stand and plant height with this sowing date. The significant effect of dates of sowing on number leaves per plant was also recorded by Bachho et al (2017). Adam and Jahan (2019) observed maximum number of leaves per plant from November 15th sown crop.

Interaction effect (V×T): Both the varieties show best performance with 15th November sowing date. The variety Unnat PBW 343 gives maximum number of leaves per plant with 15th November sowing at 60 days after sowing (64.00) and maturity (4.56). At maturity the variety Unnat PBW 343 gives 19.95 per cent higher number of leaves par plant as compared to variety PBW 502 with 15th November sowing. Both the varieties give minimum number of leaves per plant with 15th December sowing date. Adam and Jahan (2019) observed maximum number of leaves per plant with combination of BARI Gom-25 and 15th November of sowing date.

Number of Tillers per Plant

Effect of varieties: The plants of variety Unnat PBW 343 (V_1) produced significantly higher number of tillers per plant (14.01 and 9.10) as compared to variety PBW 502 *i.e.* 13.05 and 8.50, at 60 days after sowing and maturity, respectively. Yusuf et al (2019) observed significant variation among the varieties for number of tillers per plant.

Effect of date of sowing: Number of tillers per plant shows decrease trend with any deviation from ideal sowing condition. The highest number of tillers per plant was recorded in crop sown on 15th November which was 16.08 and 29.97 % higher at 60 days after sowing and maturity, respectively, than lowest recorded with 15th December sowing. It might be due to less temperature during germination and initial growth results less number of tillers developed in plants. These findings are also in agreement with the finding of Tahir et al (2009).

Interaction effect (V×T): The variety Unnat PBW 343 sown on 15 November showed highest number of tillers per plant at 60 days after sowing (15.27) and maturity (10.00) then all other treatments combinations. Adam and Jahan (2019) also found significant effects of varieties and sowing time on number of tillers per plant.

Dry matter accumulation (g/plant)

Effect of varieties: Unnat PBW 343 accumulates higher amount of dry matter (71.11 and 175.79 g per plant) than variety PBW 502 (70.32 and 174.21 g per plant) at 60 days after sowing and maturity, respectively. These findings are in agreement with El-Habbal et al (2008) and El-Temsah et al (2014).

Effect of dates of sowing: The wheat plants accumulates maximum dry matter (77.63 and 186.37 g/plant) at 60 days after sowing and maturity, respectively, when sown on 15th November. The dry matter accumulation in plants decrease with early and late sowing then this optimum sowing date of crop. The minimum dry matter accumulation was with 15th December date of sowing at both the crop growth stages. El-Temsah et al (2014) recorded maximum dry matter accumulation with 1st November sowing date.

Interaction effect (V×T): The environmental conditions and genotypes of crop variety both are responsible to influence the dry weight of plants. Both the varieties accumulates maximum dry matter with 15th November sowing, but variety Unnat PBW 343 accumulates 2.30 per cent and 2.77 per cent higher dry matter at 60 days after sowing and maturity, respectively, with 15th November sowing (V_1T_2) than variety PBW 502 and 15th November sowing (V_2T_2). The minimum dry matter accumulation was recorded (66.33 and 165.80 g/plant) at 60 days after sowing and maturity, respectively, with interaction of variety PBW 502 and 15th December date of sowing (V_2T_5). These findings are also in agreement with El-Temsah et al (2014).

Spike Length (cm)

Effect of varieties: Varieties show non-significant variation with respect to spike length of wheat crop.

Effect of dates of sowing: Significant difference in spike length were with different sowing dates of crop. Crop which sown on 15th November produce maximum 22.63 per cent longer spike length than the crop sown on 15th December which produce minimum length of spike (11.21 cm). The spike length of crop gradually decreased with the delay in sowing time from 15th November to 15th December. It might be due to the crop got lower temperature and photoperiod during late growth stage and also got less time period for growth and development of plant which ultimately affect the spike length. Mattas et al (2011) revealed that the ear length is mainly controlled by genotype of the variety and by prevailing environmental conditions of the area during the crop production and thus it shows variation. Pathania et al (2018) found higher length of spike with 20th November sowing.

Interaction effect (V×T): The interaction of varieties and sowing dates shows significant effect of on length of spike. The maximum spike length (14.53 cm) was recorded with interaction of variety Unnat PBW 343 and 15th November sowing (V_1T_2), which was statistically at par to the interaction of variety PBW 502 and 15th November sowing (V_2T_2) (14.46 cm). The minimum length of spike was recorded with interaction of variety Unnat PBW 343 and 15th December sowing (11.10 cm).

Number of Grains per Spike

Effect of varieties: The variety Unnat PBW 343 (V_1) produced 2.84 per cent significantly higher number grains per spike than variety PBW 502 (V_2). This variation may be due to genetic variability of these varieties. The significant variation among varieties for number of grains per spike was also reported by Tahir et al (2009).

Effect of date of sowing: The data recorded on number of grains per ear exhibited decrease trend with early and delayed sowing than the optimum time. The maximum number of grains per spike was in plants which sown on 15thNovember (74.30) and was significantly higher than all other sowing dates. The minimum number of grains per plant was recorded in plants which sown on 15th December (T_5) (59.22). The higher number of grains per spike might be due to higher growth and development of plants of 15th November sowing, which results higher synthesis of food materials and ultimately higher number of grains per spike. It was also due to longer length of spike with this sowing date. Pathania et al (2018) also significant higher number of grains per spike with 20th November sowing.

Interaction effect (V×T): The significantly highest number of grains per spike was recorded with variety Unnat PBW 343 sown on 15th November (V_1T_2) (73.15) while, lowest with variety Unnat PBW 343 sown on 15th December (V_1T_5) (59.25). Adam and Jahan (2019) also found significant effects of varieties and sowing dates on number of grains per spike.

Test Weight (g)

Effect of varieties: The data indicated significant difference in test weight of varieties. The higher test weight was in variety Unnat PBW 343 (V_1) (37.38 g) than the variety PBW 502 (V_2) (36.07 g). The superiority of Unnat PBW 343 seems to be on account of efficient translocation of metabolites towards grain development. These results are in close conformity to the findings of Mattas et al (2011).

Effect of date of sowing: Test weight was recorded highest in the crop sown on 15th November (39.72g) which was significantly higher than all other treatments of sowing dates. This might be due to the fact that under late sown conditions after 15th November, the grains were forced to mature and dry at maturity time because of sudden rise in temperature coupled with hot wind. Thus, the grains obtained from 15th December sown crop were small and shrivelled, which results lower test weight. The timely sown crop gets an advantage of getting sufficient time for grain development and maturation. Timely sown crop also get ideal temperature and photoperiod for bold grain development. Shirpukar et al (2008) also reported that timely sowing gave higher test weight as compared to delayed sowing.

Interaction effect (V×T): The test weight of wheat crop differs significantly to the interaction of varieties and sowing dates. The interaction of Unnat PBW 343 with 15th November sowing (39.27 g) gives the highest test weight among all the interactions and was statistically at par to interaction of variety PBW 502 with 15th November sowing *i.e.* 38.82 g. The minimum test weight recorded (35.11 g) with interaction of variety PBW 502 with 15th December sowing. (V_2T_5).

Grain Yield (q/ha)

Effect of varieties: The grain yield was varied significantly with varieties. The variety Unnat PBW 343 (36.60 q/ha) produces 4.37 per cent higher grain yield than variety PBW 502 (35.00 q/ha). High yield of Unnat PBW 343 may be attributed to its higher vegetative growth and yield contributing characters like plant height, number of tillers per plant, spike length, number of grains per plant and test weight. The higher vegetative growth may results higher production of food material and ultimately higher grain

Table 1. Effect of varieties and sowing dates on vegetative characters of wheat

Treatments	Plant height (cm)		Number of leaves per plant		Number of tillers plant		Dry matter accumulation	
	60 DAS	Maturity	60 DAS	Maturity	60 DAS	Maturity	60 DAS	Maturity
Varieties								
V_1	48.74	100.20	61.83	3.55	14.01	9.10	71.11	175.79
V_2	48.63	97.32	61.84	2.76	13.05	8.50	70.32	174.21
CD (p=0.05)	NS	0.62	NS	0.27	0.28	0.47	0.78	0.76
Sowing dates								
T_1	47.73	99.05	61.61	3.16	13.47	9.68	66.61	170.70
T_2	51.10	101.44	63.87	4.10	15.36	10.71	77.63	186.37
T_3	49.75	100.99	63.20	3.40	14.72	9.91	74.31	180.01
T_4	47.97	98.09	61.64	2.79	13.63	7.96	68.68	170.22
T_5	46.88	96.73	58.86	2.32	12.89	7.50	66.32	167.70
CD (p=0.05)	0.76	0.98	1.04	0.43	0.45	0.74	1.23	1.20
Interaction effect (varieties x Sowing dates)								
V_1T_1	47.85	100.14	62.62	3.69	13.22	9.28	68.23	171.78
V_1T_2	51.12	103.38	64.00	4.56	15.27	10.00	78.54	189.00
V_1T_3	50.03	102.45	63.76	3.70	13.88	9.30	74.57	176.79
V_1T_4	47.84	100.39	62.30	3.02	12.94	7.90	67.83	171.79
V_1T_5	46.87	98.84	56.27	2.79	12.37	7.60	66.37	169.60
V_2T_1	47.61	97.96	60.61	2.64	12.97	8.87	64.99	169.60
V_2T_2	51.09	99.49	63.87	3.65	15.19	9.29	76.73	183.75
V_2T_3	49.48	98.54	63.20	3.10	13.03	8.69	74.05	183.22
V_2T_4	48.11	95.79	61.64	2.56	12.24	7.89	69.53	168.65
V_2T_5	46.89	94.82	58.86	2.04	11.84	7.82	66.33	165.80
CD (p=0.05)	1.08	1.39	4.39	0.44	0.64	1.05	1.74	1.70

development. These findings are similar to Shirpurkar et al (2008).

Effect of date of sowing: The significantly highest grain yield was obtained in crop sown on 15th November (43.34 q/ha) followed by crop sown on 25th November (40.00 q/ha) and 05th November (39.00 q/ha) November. The lowest yield was (29.67 q/ha) in crop which sown on 15th December (T_5). It might be due to suitable environmental conditions received by crop plants for their growth and yield contributing characters ultimately yield of crop. Similar results have also been reported by Shirpukar et al (2007). Pathania et al (2018) recorded significantly higher yield of wheat with 20th November sowing.

Interaction effect (V×T): The significantly higher yield was recorded (42.67 q/ha) with interaction Unnat PBW 343 sown on 15th November (V_1T_2). It was statistically at par to the interaction of variety PBW 502 and 15th November sowing (V_2T_2) (42.01 q/ha). The lowest yield was recorded (27.00 q/ha) with interaction of variety PBW 502 and 15th December sowing (V_2T_5). Adam and Jahan (2019) also found significant interaction effects of variety and sowing dates on yield of wheat.

Harvest Index (%)

Effect of varieties: The higher harvest index was recorded in PBW 502 (34.06 %) than the Unnat PBW 343 (33.78 %), however, the variation was non-significant.

Effect of dates of sowing: Harvest index significantly differs among the different dates of sowing and was maximum in crop sown on 15th November (T_2) (.93 %) followed by 05th November (T_1) sowing (35.59 %.) This maximum harvest index was 17.79 per cent higher than minimum on 15th December sowing (T_5) (30.36 %). Adam and Jahan (2019) also found maximum harvest index on 15th November sowing.

Interaction effect (V×T): The highest harvest index was r (36.73 %) with interaction of PBW 502 with 15th November sowing (V_2T_2) which was statistically at par to the combination of Unnat PBW 343 with 15th November sowing (V_1T_2) (36.24 %), PBW 502 with 05th November sowing (V_2T_1) *(* 35.64 %) and Unnat PBW 343 with 05th November sowing (V_1T_1) (35.61 %). The lowest harvest index was with the interaction of PBW 502 and 15th December sowing (V_2T_5) (30.18 %). These finding have a close conformity with the findings of Adam and Jahan (2019).

Table 2. Effect of varieties and sowing dates on yield and yield contributing characters of wheat

Treatments	Ear length (cm)	No. of grains /ear	Test weight (g)	Grain yield (q/ ha)	Harvest index (%)
Varieties					
V_1	13.00	66.13	37.38	36.60	33.78
V_2	12.80	64.25	36.07	35.00	34.06
CD (p=0.05)	NS	0.63	0.42	1.08	NS
Sowing dates					
T_1	13.13	68.34	37.13	39.00	35.59
T_2	14.49	74.30	39.72	43.34	36.93
T_3	13.42	66.03	37.33	40.00	34.86
T_4	12.26	60.78	37.05	32.00	31.11
T_5	11.21	59.22	35.70	29.67	30.36
CD (p=0.05)	0.35	1.00	0.66	1.71	1.15
Interaction effect (varieties x Sowing dates)					
V_1T_1	13.46	67.85	36.36	37.01	35.61
V_1T_2	14.53	73.15	39.27	42.67	36.24
V_1T_3	13.06	65.22	36.38	38.01	34.07
V_1T_4	11.88	61.23	36.22	32.00	32.20
V_1T_5	11.10	59.25	35.40	28.40	30.27
V_2T_1	12.81	65.85	35.60	37.00	35.64
V_2T_2	14.46	70.01	38.82	42.01	36.73
V_2T_3	13.78	64.41	35.43	37.00	34.47
V_2T_4	12.65	61.69	35.40	32.00	33.28
V_2T_5	11.32	59.29	35.11	27.00	30.18
CD (p=0.05)	0.49	1.41	0.94	2.42	1.63

CONCLUSION

Among different dates of sowing, 15th November sowing is best for both varieties but the yield potential with variety Unnat PBW 343 is better than variety PBW 502. Hence, we can say that the variety Unnat PBW 343 sown on 15th November is best for higher yield of wheat.

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Coupling Effect of Phosphorus with Organic Manures and Bioinoculant on Growth and Yield of Black Gram (*Vigna mungo* (L.) Hepper) in Black Calcareous Soil

V. Suthakar, R. Indirani[1], P. Kannan, M. Mohamed Roshan Abu Firnass and P. Niharika

Agricultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Madurai-625 104, India
[1]Agricultural College and Research Institute, Chettinad-630 102, India
E-mail: saisuthakar007@gmail.com

Abstract: To evaluate the effect of phosphorus in conjoint with organic manures and bioinoculant for optimizing the phosphorus availability in calcareous soil, a field experiment was carried out in Kalligudi block of Madurai district using black gram (VBN 8) as a test crop. Twelve treatments were formulated with different combinations of vermicompost, farmyard manure, *Bacillus megaterium* (phosphorus solubilizing bacteria) and phosphorus fertilizer. Among the different combinations, application of 100% of P_2O_5 on soil test crop response (STCR) basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} with a recommended dose of nitrogen and potassium fertilizer recorded the maximum plant height (43.85 cm), root length (23.82 cm), nodules $plant^{-1}$ (27.42), dry matter production (2349 kg ha^{-1}), number of pods $plant^{-1}$ (28.52), seeds pod^{-1} (6.98), 100 seed weight (4.49 g), grain yield (936 kg ha^{-1}) and haulm yield (1472 kg ha^{-1}) at harvest stage. The lowest growth and yield attributes were recorded in absolute control. Application of organic manures and bioinoculant along with inorganic fertilizer in black calcareous soil led to a greater yield of black gram of 35.9% than the application of inorganic fertilizer alone. The study concluded that the application of phosphorus fertilizer along with organic manures and phosphorus solubilizing bacteria (*Bacillus megaterium*) in calcareous soils improves the phosphorus use efficiency and ultimately it will enhance the growth and yield of black gram.

Keywords: Phosphorus, Calcareous soil, *Bacillus megaterium*, Vermicompost

Black gram (*Vigna mungo* (L.) Hepper) is one of the most highly prized pulse crops occupying a unique position in Indian agriculture. India is the leading producer and consumer of black gram in the world. About 70% of the world's black gram production is grown in India. In 2020-21, India produces around 24.5 lakh tonnes of black gram from 4.6 million hectares of area with average productivity of 533 kg ha^{-1} (Black gram outlook 2021). Nearly 19% of India's total pulse acreage is used to grow black gram, which makes up 23% of India's total pulse production. Various environmental factors such as light, water, temperature, and nutrient availability have a significant impact on the growth and development of black gram. Phosphorus deficiency in soil has a negative influence on legume production because it is necessary for energy transformation in nodules, root growth and development and enhanced nitrogen fixation (Udvardi and Poole 2013), photosynthesis, nucleic acid synthesis, resistance to soil-borne root diseases and seed production (Akram et al 2017). As a result, P-deficient soil and limited availability of phosphorus impose significant constraints on the productivity of crops (Zhang et al 2014).

The majority of pulses in India are cultivated in low fertile and problematic soils. In general pulse crops mostly prefer neutral soil reactions and are extremely sensitive to acidic, saline, and alkaline soil conditions (Singh et al 2013). In the background of agricultural problem soils, calcareous soils generally contain high amount of calcium carbonate content which has a significant impact on soil properties related to crop growth. Most soil nutrients, such as N, P, K, S, Zn, Fe, Mn, Cu, and B are often less available to plants due to the high pH and $CaCO_3$ content in calcareous soil (FAO, 2020). The $CaCO_3$ in calcareous soil reacts with native and applied phosphorus and forms the calcium phosphate compounds of lower solubility ($CaCO_3 + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2 + 3CO_2\uparrow$). Application of phosphorus fertilizers at normal rates and with conventional methods in calcareous soil may not give optimal crop yield and quality. Improving crop production in calcareous soil requires increasing phosphorus use efficiency through appropriate P management measures. The conjoint application of organic manures and bioinoculant along with inorganic phosphorus fertilizer was found to increase the efficiency of applied phosphorus fertilizer in calcareous soil. Phosphate solubilizing bacteria and organic manures application are promising strategies to increase the bioavailability of insoluble soil phosphorus for plant use by producing organic acids, thereby increasing P solubility (Alori et al 2017). Keeping foregoing in mind, a field experiment was carried out to investigate the potential of using organic manures and phosphorus solubilizing bacteria (PSB) in conjunction with phosphorus fertilizer to improve black gram growth and yield in calcareous soil.

MATERIAL AND METHODS

Experimental site: A field trial was conducted in a farmer's field in Kalligudi block (9.65° N 77.92° E) of Madurai district, Tamil Nadu state during 2021-22. The experimental site received a mean annual rainfall of 840 mm and mean minimum and maximum temperature of 21.6°C and 39°C. The experimental site belongs to the Peelamedu soil series. According to USDA soil taxonomy, it has been classified as "Fine clayey montmorillonitic isohyperthermic *Typic Chromustert*".

Treatment details: The experimental field was laid out with an individual plot size of 20 m^2 (5×4 m) in a randomized block design with three replications. VBN 8 black gram was used as a test crop. Twelve treatments were followed with a combination of farmyard manure, vermicompost, *Bacillus megaterium* and chemical fertilizer (Table 1). Except for T_1, T_2, T_3 and T_8, all the treatments received soil test crop response-based N and K_2O as basal. Urea, single super phosphate (SSP) and muriate of potash (MOP) were used as a source of nitrogen, phosphorus and potassium, respectively.

Preparation of phosphorus fertilizer in conjoint with organic manures: To make enriched phosphorus fertilizer, two different sources of organic manures *viz.,* vermicompost and farmyard manure were taken and mixed with phosphorus fertilizer in different ratios *viz.,* 100% of P_2O_5 on STCR basis mixed with farmyard manure (1:10 ratio), 75% of P_2O_5 on STCR basis mixed with farmyard manure (1:10 ratio), 100% of P_2O_5 on STCR basis mixed with vermicompost (1:5 ratio) and 75% of P_2O_5 on STCR basis mixed with vermicompost (1:5 ratio). These combinations were prepared and kept for incubation at 60% moisture content in grow bag over a period of one month.

Table 1. Treatment details

Treatment	Details
T_1	Absolute control
T_2	Recommended N, P_2O_5, K_2O @ 25:50:25 kg ha^{-1}
T_3	100% of P_2O_5 on STCR basis alone
T_4	100% of P_2O_5 on STCR basis incubated for 30 days with farm yard manure at 1:10 ratio
T_5	75% of P_2O_5 on STCR basis incubated for 30 days with farm yard manure at 1:10 ratio
T_6	100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio
T_7	75% of P_2O_5 on STCR basis incubated with vermicompost for 30 days at 1:5 ratio
T_8	100% of P_2O_5 on STCR basis + PSB @ 2 kg ha^{-1}
T_9	T_4+ PSB @ 2 kg ha^{-1}
T_{10}	T_5+ PSB @ 2 kg ha^{-1}
T_{11}	T_6 + PSB @ 2 kg ha^{-1}
T_{12}	T_7 + PSB @ 2 kg ha^{-1}

Data collection and analysis: For initial soil characterization, soil samples were collected from the field at 0 to 15 cm depth. The collected soil samples were shade dried and sieved through a 2 mm sieve. To estimate organic carbon content, the samples were sieved through a 0.2 mm sieve. The processed samples were analyzed for texture (International pipette method, Piper, 1966), bulk density, particle density, pore space (Core sampler method, Gupta and Dakshinamoorthy,1980), pH (Potentiometry, Jackson 1973), electrical conductivity (Conductometry, Jackson 1973), cation exchange capacity (CEC) (Neutral normal ammonium acetate method, Jackson 1973), anion exchange capacity (AEC) (Magnesium sulphate – Barium chloride method, Gillman, 1979), organic carbon (Dichromate wet digestion method, Walkley and Black, 1934), free $CaCO_3$ (Rapid titration method, Piper 1966), available nitrogen (Alkaline permanganate method, Subbaiah and Asija 1956), available phosphorus (Olsen method, Olsen, 1954), available potassium (Neutral normal NH_4OAc method, Stanford and English 1949), and DTPA extractable micronutrients Zn, Mn, Fe and Cu (Atomic Absorption Spectrophotometer, Lindsay and Norvell 1978). The initial soil properties are given in Table 2. The dataset collected was statistically analyzed with the AGRES software package.

Growth Attributes

Plant height: Co-application of phosphorus fertilizer with organic manures and bioinoculant significantly influenced the plant height at different growth stages of black gram (Table 3). The plant height ranged from 12.08 to 21.51, 17.30 to 35.01 and 20.52 to 43.85 cm at vegetative, flowering and harvest stages, respectively. The tallest plant was recorded in the treatment supplied with 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} at vegetative, flowering and harvest stage which was followed with the treatment received 75% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} at vegetative, flowering and harvest. The shortest plant of 12.08, 17.30 and 20.52 cm at vegetative, flowering and harvest stage, respectively was found with absolute control. The synergistic effect of phosphorus, vermicompost and PSB application might have enhanced the root activity and root nodulation of plants, resulting in higher uptake of plant nutrients in adequate quantities and increased plant height. This line was in

Table 2. Initial soil properties

Particulars	Value
Mechanical composition	
Clay (%)	34.76
Silt (%)	20.41
Fine sand (%)	17.01
Coarse sand (%)	25.68
Texture class	Sandy clay loam
Physical properties	
Bulk density (Mg m^{-3})	1.34
Particle density (Mg m^{-3})	2.50
Porosity (%)	41
Physico-chemical properties	
pH	8.32
EC (dSm^{-1})	0.18
CEC (c mol (p^+) kg^{-1})	25.62
AEC (c mol (p^-) kg^{-1})	2.34
Chemical properties	
Total Sesquioxide (%)	5.32
Free $CaCO_3$ (%)	7.63
Organic Carbon (g kg^{-1})	3.8
Alkaline $KMnO_4$ - N (kg ha^{-1})	234
Olsen - P (kg ha^{-1})	10.34
NH_4OAc - K (kg ha^{-1})	214.24
$CaCl_2$ - Sulphur (ppm)	13.92
Exchangeable Calcium (c mol (p^+) kg^{-1})	13.97
Exchangeable Magnesium (c mol (p^+) kg^{-1})	6.42
DTPA extractable - Fe (mg kg^{-1})	2.33
DTPA extractable - Mn (mg kg^{-1})	7.37
DTPA extractable - Zn (mg kg^{-1})	1.24
DTPA extractable - Cu (mg kg^{-1})	2.54

accordance with the findings of Kuntyastuti and Sutrisno (2017) and Hu et al (2014). Patel et al (2020) also reported that phosphorus promotes the new cell formation and elongation of cells, increases plant vigour and hastens leaf development, which aids in the harvesting of more solar energy and the better utilization of nitrogen, resulting in increased plant growth.

Root length: The phosphorus fertilization along with organic manures and bioinoculant significantly influenced the root length at different growth stages of black gram (Table 3). Phosphorus fertilization along with organic manures and bioinoculant upgraded the root length and maximum root length of 14.58, 19.37 and 23.82 cm was observed with the treatment received 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} at vegetative, flowering and harvest stage, respectively. The least root length of 6.79, 10.84 and 11.32 cm was with absolute control at vegetative, flowering and harvest stages, respectively. Vermicompost and PSB combination results in a higher root length this could be due to the addition of inorganic P alone is converted into a number of reaction products in soil, the bulk of which were low soluble orthophosphates. When combined with vermicompost and PSB, the fixed P is dislodged resulting in higher phosphorus bioavailability (Naik and Mehera 2022), which in turn increases the root length of black gram. Yadav et al (2019) reported that, the application of vermicompost with bioinoculant and inorganic fertilizer plays a critical part in root development and proliferation, which leads to improved nodule formation and nitrogen fixation by supplying the assimilates to the roots as well as a better rhizosphere environment for root growth and development. The addition of vermicompost might have improved the aeration,

Table 3. Effect of phosphorus in conjoint with organic manures and bioinoculant on plant height and root length of black gram

Treatments	Plant height (cm)			Root length (cm)		
	Vegetative stage	Flowering stage	At harvest	Vegetative stage	Flowering stage	At harvest
T_1	12.08	17.30	20.52	6.79	10.84	11.32
T_2	14.79	21.71	27.98	9.78	14.03	16.20
T_3	13.35	18.21	22.08	7.31	11.51	12.07
T_4	16.68	26.06	32.89	11.41	15.75	18.43
T_5	15.76	24.10	30.93	10.60	14.96	17.31
T_6	18.42	28.46	35.50	12.17	16.65	19.81
T_7	17.39	26.53	33.57	11.46	15.92	18.69
T_8	13.78	19.41	23.96	8.75	12.34	14.29
T_9	20.30	32.76	40.16	13.62	18.45	22.36
T_{10}	19.41	30.71	37.99	12.88	17.68	21.20
T_{11}	21.51	35.01	43.85	14.58	19.37	23.82
T_{12}	20.69	33.25	40.90	13.69	18.52	22.73
CD (p=0.05)	0.73	0.85	1.54	0.50	0.65	0.69

drainage, and created a desirable soil environment for deeper root penetration and better nutrient extraction from the soil.

Root nodules: The application of inorganic phosphorus fertilizer along with organic manures and bioinoculant had a positive effect on nodule count at the flowering stage of black gram (Table 4). Among the various treatments, the root nodule count of 27.42 was found to be superior in the treatment received 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} at the flowering stage which was followed by the addition of 75% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} (25.28). The lowest nodule count of 7.39 was recorded in absolute control. The relatively higher phosphorus availability in the rhizosphere region might have aided the *Rhizobium* activity which resulted in a greater number of nodules $plant^{-1}$ (Kumar and Yadav 2018). This might be the reason for a higher number of nodules in the treatment received phosphorus than in absolute control. Rekha et al (2018) reported that the increase in the number of nodules $plant^{-1}$ could be attributed to more favourable conditions for microorganisms or the formation of a conducive soil for microbe proliferation by the application of organic manures with inorganic fertilizers. Better nodulation in PSB inoculated treatment might be due to increased P availability through PSB, which enhances root nodule count and biological nitrogen fixation (Nadeem et al 2018).

Dry matter production of black gram: The integrated application of phosphorus fertilizer along with organic manures and bioinoculant had a significant effect on the dry matter production of black gram (Table 4). The dry matter production was extended from 630 to 1235, 951 to 1855 and 1200 to 2349 kg ha^{-1} at vegetative, flowering and harvest stages, respectively. Among the treatments, T_{11} (100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1}) recorded significantly a higher dry matter production of 1235, 1855 and 2349 kg ha^{-1} at vegetative, flowering and harvest stage, respectively and this was followed by T_{12}. The lowest dry matter production was noted in control (T_1). The highest dry matter accumulation in the above-mentioned treatment might be due to the combined application of organic manures with phosphorus fertilizer to the crop which increased the availability of nutrients by promoting early root growth, resulting in increased nutrient absorption from deeper layers of soil and ultimately enhanced the vegetative growth of plants. A similar result was also reported by Banotra et al (2021). Increased phosphorus availability might have increased nodulation activity, cell development, plant vigour, and vegetative growth, which might be one of the reasons for the highest dry matter production in the treatment received phosphorus fertilizer than absolute control. These results are in agreement with those of Chena et al (2017) and Bekele et al (2019).

Yield Attributes of Black Gram

Number of pods $plant^{-1}$ and number grains pod^{-1}: The number of pods $plant^{-1}$ and grains pod^{-1} were found statistically significant due to the application of various combinations of organic manure, bioinoculant and

Table 4. Effect of phosphorus in conjoint with organic manures and bioinoculant on nodules $plant^{-1}$ and dry matter production (kg ha^{-1}) of black gram

Treatments	Number of nodules $plant^{-1}$	Dry matter production (kg ha^{-1})		
	Flowering stage	Vegetative stage	Flowering stage	At harvest
T_1	7.39	630	951	1200
T_2	14.39	822	1207	1539
T_3	8.26	669	1006	1264
T_4	18.25	947	1401	1768
T_5	16.46	889	1318	1670
T_6	20.42	1028	1532	1920
T_7	18.72	972	1446	1817
T_8	11.76	722	1077	1376
T_9	25.11	1154	1717	2176
T_{10}	22.31	1099	1634	2071
T_{11}	27.42	1235	1855	2349
T_{12}	25.28	1177	1758	2228
CD (p=0.05)	0.83	36.29	54.66	62.42

phosphorus fertilizer over control (Table 5). Application of 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} produced the maximum number of pods and grains $plant^{-1}$ of 28.52 & 6.98 respectively. Treatment which received RDF alone produced a comparatively lower number of pods and grains $plant^{-1}$ of 16.73 & 4.68 respectively. This might be due to the use of inorganic fertilizers increased the availability of essential nutrients to crop plants, whereas the use of organic manures, notably vermicompost, increased the activity of microorganisms in soils, which improves the nutrient solubility and availability to the plants. As a result, the combined effect of organic and inorganic nutrient sources improved the yield attributes of black gram. Sonnet et al (2020) reported that phosphorus fertilization stimulates the plant for flowering and fruiting which leads to the development of more pods $plant^{-1}$. Application of phosphorus resulted in increased carbohydrate accumulation and their remobilization to reproductive parts of the plant, being the closest sink resulted in increased flowering, fruiting and seed formation (Shamsurahman et al 2020). This might be the reason for a higher pods $plant^{-1}$ in phosphorus fertilized plots than in absolute control.

Test weight: The phosphorus fertilization along with organic manures and bioinoculant significantly influenced the test weight of black gram (Table 5). The maximum test weight of 4.49 g was observed in the treatment 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} (T_{11}) closely followed by T_{12}. The least test weight of 3.80 g was recorded in absolute control. This might be due to the reason that, vermicompost is an excellent source of N, P, K, and organic acids which are released during the decomposition of vermicompost and played an important role in improved nutrient availability in both early and later stages of crop growth. Sharma et al (2021) stated that phosphorus fertilization had increased the plant photosynthesis activity and aided in the development of a more extensive root system, allowing the plant to extract more water and nutrients from higher soil depth, which resulted in improved plant growth and yield attributes.

Grain yield: The positive response was observed with the application of phosphorus fertilizer in conjoint with organic manures and bioinoculant as compared to the application of inorganic P fertilizer alone (Table 5). The maximum grain yield of 936 kg ha^{-1} was registered with T_{11}. The integration of vermicompost and bioinoculant along with phosphorus fertilizer has improved the black gram yield by 35.89% over the use of a recommended dose of fertilizer alone. The minimum grain yield of 432 kg ha^{-1} was recorded in absolute control (T_1). The highest grain yield of the treatments received organic manures and bioinoculant might be due to the ability of PSB and organic manures to secrete organic acids for solubilization of precipitated phosphorus (calcium phosphate) and lowering the pH of the surrounding bulk and rhizosphere soil which creates a favourable environment for higher phosphorus availability and grain yield. This finding is in agreement with the findings of Wahid et al (2020). Singh et al (2018) reported that the increased translocation might have occurred as a result of increased potassium and phosphorus uptake, which are responsible for the rapid and easy translocation of photosynthates from source to sink which in turn increased the grain yield. PSB has been found to produce

Table 5. Effect of phosphorus in conjoint with organic manures and bioinoculant on yield attributes of black gram

Treatments	Number of pods $plant^{-1}$	Number of grains pod^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
T_1	8.90	4.01	3.80	432	882
T_2	16.73	4.68	3.99	600	1065
T_3	9.78	4.19	3.85	456	926
T_4	21.04	5.23	4.14	728	1185
T_5	19.37	4.97	4.09	682	1131
T_6	22.91	5.62	4.23	781	1268
T_7	21.22	5.36	4.16	739	1210
T_8	11.14	4.41	3.91	497	975
T_9	26.75	6.18	4.41	880	1383
T_{10}	25.16	5.92	4.35	837	1326
T_{11}	28.52	6.98	4.49	936	1472
T_{12}	26.92	6.23	4.43	891	1414
CD (p=0.05)	0.83	0.17	0.04	24.25	42.04

vitamins (Vitamin A, B_1, B_2, B_3, C and E), Indole Acetic Acid (IAA), Naphthalene acetic acid and gibberellin-like compounds. These growth factors, combined with improved nutritional conditions might have played a significant role in increasing grain yield (Sharma et al 2021). This might be the reason for a higher grain yield in the treatments inoculated with PSB than in non-inoculated treatments.

Haulm yield: The application of various treatments had a significant effect on haulm yield of black gram and it extended from 882 to 1472 kg ha^{-1} (Table 5). Among the treatments, T_{11} (100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1}) registered significantly the highest haulm yield of 1472 kg ha^{-1} and this was followed by T_{12} with the value of 1414 kg ha^{-1}. The lowest haulm yield was noted in absolute control (882 kg ha^{-1}). An increased in haulm yield of 27.64% was recorded by the application of 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} over recommended dose of fertilizer alone. This might be due to the production of growth-promoting substances and organic acids during organic manures decomposition might have facilitated easy availability and absorption of macro and micronutrients. This might be the reason for higher haulm yield in the treatment received organic manures, bioinoculant and inorganic P fertilizer than the application of inorganic phosphorus fertilizer alone. Similar finding was also reported by Khan et al (2017).

CONCLUSION

Application of phosphorus in conjoint with bioinoculant and organic's sources significantly enhanced the growth and yield attributes of black gram in calcareous soil. The application of 100% of P_2O_5 on STCR basis incubated for 30 days with vermicompost at 1:5 ratio + PSB @ 2 kg ha^{-1} with nitrogen and potassium fertilizer in calcareous soil significantly increases the growth and yield of black gram. Application of organic manures with PSB and chemical fertilizers reduces the phosphorus fixation and also solubilizes the fixed phosphorus in calcareous soil as calcium phosphate by the production of various organics acid which leads to a higher phosphorus availability, growth and yield of crops.

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Impact of FYM and Micronutrients on Nutrient Content, Uptake, Yield and Economic Attributes of Direct Seeded Basmati Rice

Priyanka Sanwal, R.S. Garhwal*, Sekhar Kumar, Sunil Kumar and Satender Kumar
Department of Soil Science, CCSHAU, Hisar, Haryana-125 001, India
E-mail: sanwalpriyanka2015@gmail.com

***Abstract*:** A field experiment was carried out at CCS HAU, College of Agriculture, Kaul research farm during *kharif*, 2020 to study the effect of FYM and micronutrients on nutrient content, uptake, yield and economic attributes of direct seeded basmati rice. The experiment was laid out in randomized block design with 7 treatments including each with a different combination of chemical fertilizer (RDF), farmyard manure (FYM), and micronutrients ($ZnSO_4$ and $FeSO_4$). Amongst the all treatments, 75% RDF along with FYM @ 15 t/ha resulted in the highest yield attributes (like plant height, number of effective tillers per m^2, grain yield, straw yield and harvesting index) and economic parameters (like cost of cultivation, gross return, net return and benefit-cost ratio) which was at par with 50% RDF with FYM @ 15 t/ha but statistically superior then control. Amongst micronutrient treatments, combined foliar application of zinc and iron along with RDF resulted in higher yield and highest Benefit and Cost ratio (B:C) was observed as compared to other treatments resulting in higher returns with low cost of cultivation.

Keywords: Basmati rice, Micronutrients, FYM

Rice (*Oryza sativa* L.) is one of the world's most important cereal food crops in India. It is responsible for about 45% of total food grain production in India. The rice sowing area is roughly 44 million hectares (Mha), with approximately 112.9 Million tonne (Mt) and 24.32 quantal per hectare (q/ha) production and productivity, respectively (Anonymous 2020a). Rice inhabited nearly 1.42 Mha in Haryana, with a production of 4.88 M t and a productivity of roughly 34.32 q/ha (Anonymous 2020b). Punjab and Haryana are the major basmati rice-producing states in India, accounting for roughly 80% of total basmati paddy cultivation (APEDA 2014). The standard method of rice cultivation is by transplanting, which necessitates a significant amount of water, labour, and energy. Water availability has dropped in recent years, and the water table level is rapidly dropping, limiting the extent of rice cultivation through transplanting methods in the coming years. As a result, it is extremely crucial to focus on finding out the best suitable rice cultivation practice. Direct seeding of rice (DSR) is one of the reasonable options because it can save water, reduces labour requirements, and lessens greenhouse gas (GHG) emissions, and there is no need to prepare nurseries in DSR (Kumar et al 2022).One of the prime causes of the decrease in rice production is a scarcity of micronutrients (Somaratne et al 2021). Iron (Fe) deficiency is among the most widespread micronutrient deficiencies worldwide, occurring in approximately 60% of the world's population (Vijayakumar et al 2020). It kills nearly 0.8 million people worldwide annually. Zinc (Zn) deficiency is yet another serious concern that affects approximately one-third of the worldwide people (Singh and Singh 2018). Foliar micronutrient application is the easiest and fastest method to address nutrient deficiency symptoms in plants and generate a rapid response (Fernández and Brown 2013).

Consistent use of inorganic fertilizers degrades soil conditions and lessens yield over time, whereas FYM strengthens soil Physico-chemical properties including porosity, aggregate stability, water holding capacity, nutrient recycling, organic carbon, cation exchange capacity (CEC), and so on. Organic manure inclusion into soil has been found to improve crop yield and soil fertility (Bhavani et al 2017). The use of organic manure associated with inorganic fertilizers is effective in relieving nutrient deficiency. Thus, the present investigation was carried out to investigate the impact of FYM and foliar application of micronutrients along with RDF on nutrient (N, P, and K) content, uptake, yield, and yield parameters of direct seeded basmati rice.

MATERIAL AND METHODS

The field experiment to study the impact of FYM and micronutrients on nutrient content, uptake, yield and economic attributes of direct seeded basmati rice in clay loam soil at Kaithal district of Haryana at CCS HAU, College of Agriculture, Kaul, during *Kharif* 2020. The initial soil properties are presented in Table 1. The experiment was set up in a randomised block design with seven treatments, each with a different combination of chemical fertiliser (RDF), farmyard manure (FYM), and micronutrients ($ZnSO_4$ and $FeSO_4$) with three replications (Table 2). On June 22nd, 2020, the Basmati variety CSR-30 was directly sown at a seed rate of 20 kg/ha. Nitrogen was applied in three split doses using urea, with half of the total nitrogen applied as a basal dose and the remaining half applied in two equal split doses at active tillering and panicle initiation. The full dose of phosphorus and potassium doses were applied during sowing using diammonium phosphate (DAP) and murate of potash (MOP), respectively. Two weeks prior sowing, well-decomposed FYM @ 15 t/ha was incorporated as per recommended in Haryana condition (Kavinder et al 2019). However, the average chemical compositions of NPK in FYM (0.58, 0.26 and 0.60%) and micronutrient Fe and Zn (184 and 4.67ppm). At the tillering and panicle initiation stages, two foliar sprays of iron sulphate (0.5%) and zinc sulphate (0.5%) were applied by dissolving the required amount of iron and zinc sulphate in water with urea. The crop was harvested manually at physiological maturity and then threshing was also done manually. Plant height and the number of effective tillers per m^2 were measured manually by selecting five plants at random from each plot. Plant height was measured from ground surface to the top of the ear at physiological maturity.

Table 1. Initial soil chemical properties

Soil property	Value
Bulk density (Mg/m^3)	1.34
pH	8.66
EC (dS/m)	0.11
Organic carbon (%)	0.54
Available nitrogen (kg/ha)	105
Available phosphorus (kg/ha)	21.47
Available potassium (kg/ha)	360
DTPA-Zn (ppm)	1.8
DTPA-Fe (ppm)	14.75
DTPA-Cu (ppm)	1.34
DTPA-Mn (ppm)	2.95

Table 2. Treatment details

Treatments	Nutrients levels
T_1	Control
T_2	RDF (NPK)
T_3	75% RDF + FYM @ 15 t/ha
T_4	50% RDF + FYM @ 15 t/ha
T_5	RDF + two sprays of 0.5% $ZnSO_4$
T_6	RDF + two sprays of 0.5% $FeSO_4$
T_7	RDF + two sprays of 0.5% $FeSO_4$ + two sprays of 0.5% $ZnSO_4$

*RDF- recommended dose of fertilizers

The harvest index was calculated by dividing the grain yield by the biological yield (grain yield + straw yield) and then multiplied by 100:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Plant analysis: At harvest of crop, grain and straw samples from each plots were collected, initially the samples were dried in air, and finally in oven at 60 ± 2°C for 24 hours. After that samples were ground in mini willey with stainless steel blades and stored in different polyethylene bags for the analysis of nitrogen, phosphorus, potassium, zinc, iron, manganese and copper. The determination of nitrogen, phosphorus and potassium in plant samples was done by colorimetric method using Nessler's reagent (Lindner 1944), vanado-molybdate phosphoric yellow colour method, and flame photometer respectively (Jackson 1973). The uptake of nitrogen, phosphorus, potassium, iron, zinc, manganese and copper by rice grain and straw were computed from the data on nutrients content, grain and straw yield.

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{\% nutrient content} \times \text{Yield (Grain or straw)}}{100}$$

The, net return was calculated by using gross returns and cost of cultivation:

Net returns = Gross returns − cost of cultivation

Treatment wise benefit cost (B: C) ratio was calculated using the following formula:

$$\text{B: C ratio} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

Data analysis: The crop data subjected to statistically analysis using the OPSTAT statistical software package.

RESULTS AND DISCUSSION

Yield attributes: Combining FYM or micronutrients with RDF has resulted in significant increase yield attributes as compared to control (Table 3). Rice plots fertilized with 75% RDF and FYM at 15 t/ha had the highest plant height (126.47 cm), number of effective tillers per m^2 (270.33), grain yield (34.66 q/ha) and straw yield (45.88 q/ha); at par with 50% RDF and FYM at 15 t/ha. T_5 treatment had the highest harvest index (43.33%). The plot with no fertilizer applied (T_1) had the lowest value followed by RDF (T_2). This could be due to the synergistic effect of inorganic fertilizer and FYM on plant vegetative growth, which resulted in taller plants, higher grain and straw yield, and a greater number of effective tillers per m^2 (Kumar et al 2022). In the crop, there was a positive relationship between yield attributes (plant height and number of effective tillers) and yield (grain and straw yield)

(Fig. 1). Earlier researchers also observed that applying 50% RDN through inorganic fertilizer and 50% N through FYM increased plant growth and development over RDF alone (Singh et al 2019, Meena et al 2019 and Ashwini et al 2015). Similarly, Garai et al (2014) concluded that 100% RDF along with vermicompost at 2.5 t/ha, PSB, and Azotobacter, which was at par with 75% RDF along with vermicompost at 2.5 t/ha and PSB and Azotobacter. Upinder et al (2016) found that continuous substitution of 50% NPK by green manure produced maximum rice grain and straw yields that were 16.8 and 14.8% higher than 100% NPK alone in a rice-wheat cropping system in CSK Himachal Pradesh. However, Apon et al (2018) observed that 100% RDF + 5 t/ha FYM produced the most, followed by 75% RDF + 5 t/ha FYM, and then 50% RDF + 5 t/ha FYM.

Foliar application of micronutrients (Fe and Zn) in conjunction with RDF increased yield over control and/or RDF alone (Table 3). It could be due to an increase in the availability and uptake of essential nutrients caused by Zn supply, which improves plant metabolic processes and, ultimately, crop growth. Zayed et al (2011) observed that applying micronutrients (Zn^{2+}, Fe^{2+}, and Mn^{2+}) as soil single treatments or combined treatments (Zn^{2+} + Mn^{2+}, Zn^{2+} + Fe^{2+}, Mn^{2+} + Fe^{2+}, and Zn^{2+} + Mn^{2+} + Fe^{2+}) through soil as well as foliar spray resulted in higher yield attributes over the control, especially in saline conditions. Sultana et al (2001), Ali et al (2003), and Naik and Das (2007) also found similar trend.

Nutrient content in both grain and straw- Nutrient content in terms of N, P and K in both grain and straw was significantly increased on the combined application of FYM or micronutrients with RDF over the control and/ or RDF alone (Table 4). Amongst the treatments, N, P and K content in rice grain varied from 1.08 to 1.35% with the variation of 25%, 0.46 to 0.57% with the variation of 86.81% and 0.46 to 0.58% with the variation of 26.08% respectively. The combined application of RDF with FYM @ 15 t/ha found to give the highest N, P and K content in rice grain and the least was found in plot with no fertilized treatment. In straw, N content ranged from 0.45 to 0.54%, P content ranged from 0.21 to 0.27% and K content ranged from 1.43 to 1.75% with increment of 20, 28.57 and 22.37% respectively. This might be due to synergic effect of FYM and RDF which not only results in direct supply of nutrients on their application but also helps in mineralization of native immobilized nutrients present in the soil. Because of this, nutrients are more available for plant uptake and thus increase nutrient content

Table 3. Effect of micronutrients (Zn and Fe) and FYM on yield attributes of direct seeded basmati rice

Treatments	Plant height (cm)	No. of effective tillers per m^2	Grain Yield (q/ha)	Straw Yield (q/ha)	Harvest index (%)
T_1	105.02	210.67	21.56	32.91	39.58
T_2	111.36	246.67	31.15	42.49	42.30
T_3	126.47	270.33	34.66	45.88	43.04
T_4	121.55	265.33	33.55	44.68	42.89
T_5	121.4	256.33	31.98	41.82	43.33
T_6	118.58	248.13	31.78	41.84	43.17
T_7	121.6	262.33	32.79	42.89	43.33
CD (p= 0.05)	5.40	7.82	1.38	1.45	1.81

Table 4. Effect of micronutrients (Zn and Fe) and FYM on NPK content in rice grain and straw of direct seeded basmati

Treatments	N content (%)		P content (%)		K content (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.08	0.45	0.46	0.21	0.46	1.43
T_2	1.26	0.49	0.48	0.26	0.52	1.67
T_3	1.35	0.54	0.57	0.27	0.58	1.75
T_4	1.30	0.52	0.50	0.26	0.54	1.71
T_5	1.24	0.5	0.48	0.25	0.50	1.68
T_6	1.26	0.49	0.47	0.25	0.49	1.66
T_7	1.27	0.51	0.49	0.25	0.51	1.68
CD (p= 0.05)	0.06	0.04	0.02	0.01	0.06	0.07

in plant grain and straw. These results were supported by findings of Islam et al (2018) and Sultana et al (2021).

Nutrient uptake in both rice grain and straw-The uptake of N, P, and K nutrients in grain and straw varied significantly (Table 5). In rice grain, nutrient uptake ranged from 23.21 to 43.36 kg/ha for N, 9.88 to 15.24 kg/ha for P, and 10.13 to 17.87 kg/ha for K, with a variation of 86.81%, 54.25%, and 76.40%, respectively, when compared to control. The plot with RDF and FYM @ 15 t/hahad the highest value of N and K uptake in rice grain, while the T_6 had the highest value of P uptake. The plot with no fertiliser applied (T_1) had the lowest N, P, and K uptake in rice grain. Nutrient uptake in rice straw

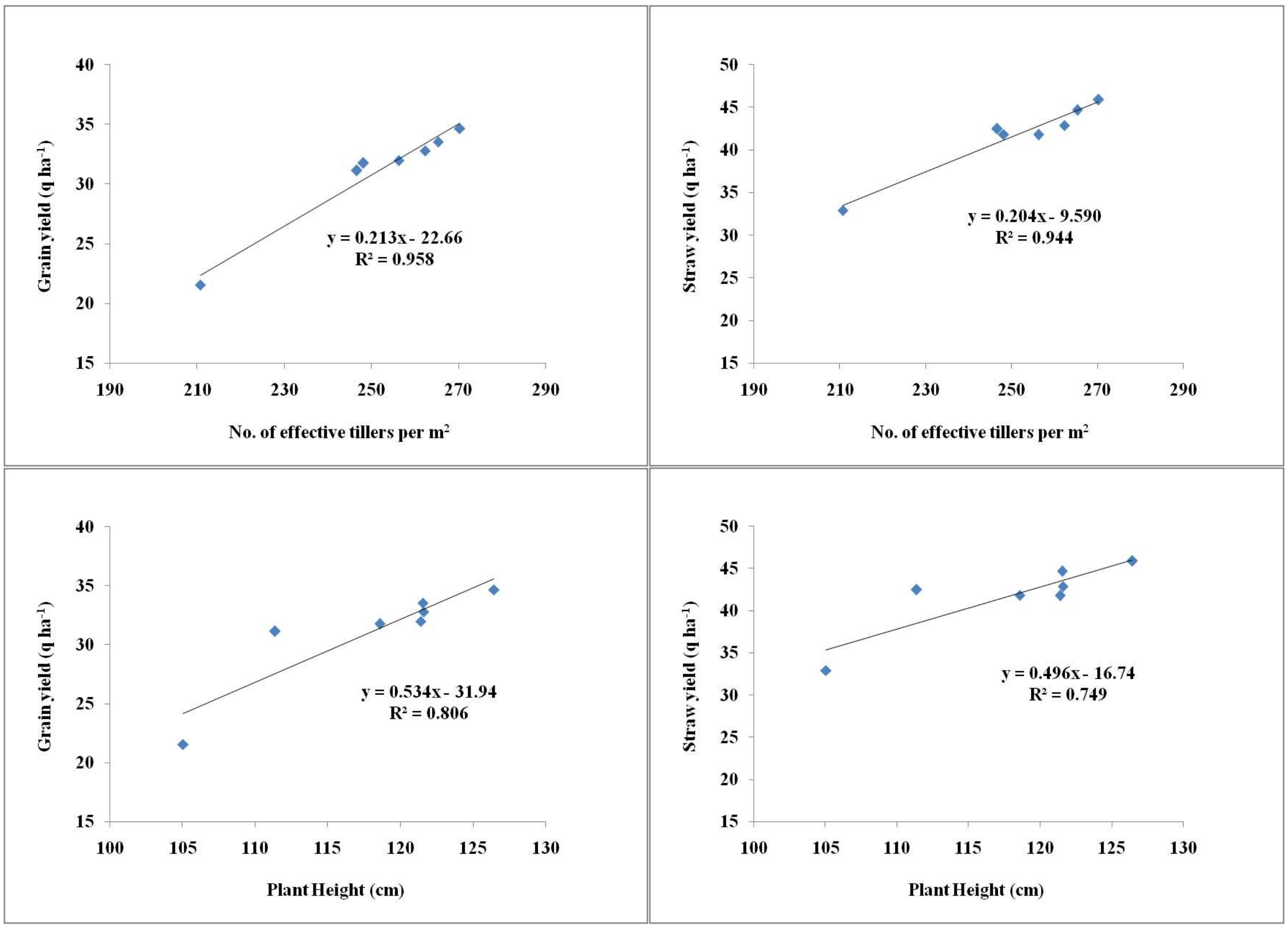

Fig. 1. Relationship between yield attributes and yield in direct seeded basmati rice

Table 5. Effect of micronutrients (Zn and Fe) and FYM on NPK uptake in rice grain and straw of direct seeded basmati rice

Treatments	N Uptake (kg/ha)		P Uptake (kg/ha)		K Uptake (kg/ha)	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1	23.21	15.07	9.88	7.03	10.13	46.29
T_2	29.81	17.92	15.03	10.05	12.22	61.09
T_3	43.36	23.65	13.41	10.95	17.87	76.65
T_4	40.82	22.18	12.96	10.19	16.60	72.95
T_5	32.45	19.36	14.21	9.84	13.05	65.16
T_6	32.70	18.96	15.24	10.91	12.84	64.24
T_7	37.45	19.95	12.75	9.7	15.00	66.24
CD (p= 0.05)	1.43	1.60	0.51	0.34	1.83	2.02

Table 6. Effect of micronutrients (Zn and Fe) and FYM on economics of direct seeded basmati rice

Treatments	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	C:B
T_1	29330	63670	34340	1: 2.17
T_2	32656	91465	58809	1: 2.14
T_3	36623	101648	65023	1: 2.58
T_4	35793	98420	62627	1: 2.57
T_5	33184	93729	60547	1: 2.31
T_6	33169	93172	60002	1: 2.31
T_7	33696	96091	62394	1: 2.56

ranged from 15.07 to 23.65 kg/ha for N, 7.03 to 10.95 kg/ha for P, and 46.29 to 76.65 kg/ha for K. The application of 75% RDF with FYM @ 15 t/ha resulted in the highest nutrient uptake in both grain and straw, followed by 50% RDF with FYM @ 15 t/ha, and the lowest in T_1. Gill and Aulakh (2018) also observed that using nitrogen from two sources, one through recommended nitrogen (RN) at 50% and the other through FYM, resulted in the highest N, P, and K uptake in both grain and straw. Pandey et al (2015) concluded that judicious use of organic fertilizer with a lower amount of recommended nitrogen (RN) significantly improved N uptake in rice (32.0 kg/ha). Srinivas et al (2010) mentioned that the combined application of FYM and chemical fertilizers significantly influenced k uptake in rice grain. The application of FYM + 50% RN and FYM + GM (Green Manure) improved crop P and K uptake, which could be due to organic acids released by the decomposition of organic materials, which increase the availability of phosphorus and potassium in the soil by the release of native P and K. Ranjitha et al (2013) also revealed that treatments receiving 50% inorganic nitrogen source (root dipping) and 50% organic nitrogen source through vermicompost (root dipping) had significantly higher NPK uptake by rice (157.9-30.7-166.0 kg/ha) when compared to 100% inorganic N source alone (136.5-23.2-125.6 kg/ha) and control (58.7-6.9-61.6 kg/ha). Furthermore, Kumar et al (2014) demonstrated that combining organic and inorganic nutrient sources significantly increased N uptake in grain and straw (36.81% and 42.81%, respectively), P uptake in grain and straw (32.62% and 31.56%, respectively), and K uptake in grain and straw (35.46% and 25.39%, respectively) over control. Wolie and Admassu (2016) also observed the same trend.

Economics: The application of FYM @ 15 t/ha or spray of micronutrients along with RDF resulted increase in economic attributes (Table 6). The range of various economic attributes like cost of cultivation varied from 29,330 to 36,623 Rs/ha, gross return varied from 63,670 to 1,10,648 Rs/ha, net return varied from 34,340 to 65,023 Rs/ha and cost-benefit ratio varied from 1:2.17 to 1:2.58. Amongst all treatments, T_3 (75% RDF + FYM @ 15 t/ha) and T_4 (50% RDF + FYM @ 15 t/ha)resulted in the higher cost of cultivation, gross return, net return and Benefit-Cost ratio. More monetary returns were observed on combined application of the organic manure and inorganic fertilizers. Meena et al (2019) and Pandey et al (2015) found that 50% RDN through inorganic fertiliser plus 50% N through FYM (T_4) produced significantly higher net returns than T_3 (75% RDN through inorganic fertiliser + 25% N through FYM). However, Koushal et al (2011) reported that during the wheat season, 100% RDF produced significantly higher yields, gross return net returns, and B : C ratios that were comparable to 75% of the recommended dose of fertilizer applied and replacing fertilizer with organic sources like vermicompost and FYM by 50% of RDN would be a better proposition for reducing chemical fertilizer use in rice and 25% in wheat.

CONCLUSION

Application of either FYM or micronutrients along with RDF resulted in significantly higher nutrient content and uptake in both grain and straw. The 75% RDF along with FYM @15 t/ha resulted in the highest yield and economic attributes, which is followed by 50% RDF along with FYM. The 50% RDF along with FYM @ 15 t/ha was a more economically feasible treatment because of reducing in the amount of inorganic fertilizer used which in turn reduces the cost of cultivation. The spray of micronutrients (either $ZnSO_4$ or $FeSO_4$ or in combination) along with RDF also enhanced yield attributes.

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Growth Analysis in Relation to Sowing Environments and Nitrogen Levels in Wheat Varieties under Irrigated Conditions of N-W Himalayas of Jammu and Kashmir

Vikas Gupta, Meenakshi Gupta[1], Sarabdeep Kour[2] and Rajeev Bharat[3]

Basmati Rice Research Centre (BRRC), SKUAST-J, Chakroi, R. S. Pura, Jammu -181 102, India
[1]Division of Agronomy, [2]Division of Soil Science and Agricultural Chemistry and [3]AICRP on Mustard, Division of PBG, SKUAST-J, Chatha-180 009, India
E-mail: vikasadr@gmail.com

Abstract: Field experiments were conducted in *rabi* 2015-16 and 2016-17 at Agromet Research Farm, SKUAST-J, Chatha, J&K to evaluate the effect of sowing environments and nitrogen levels on growth parametres and yield of wheat (*Triticum aestivum* L.) varieties. Three wheat varieties (HD 2967, RSP 561 and WH 1105), 3 sowing environments (25^{th} October, 14^{th} November and 4^{th} December) and 3 nitrogen levels (100, 125 and 150 kg/ha) were laid out in split split plot design. The results revealed that variety WH 1105 observed significantly superior growth parametres *viz.* dry matter accumulation, leaf area index, crop growth rate, specific leaf area and grain and straw yields as compared to HD 2967 and RSP 561. Variety RSP 561 recorded lowest parameters and yield. Among the sowing environments, the early sown (25^{th} October) wheat crop envisages significantly higher values of growth parametres and grain yield. Whereas, statistically notable values of the same recorded in higher dose of nitrogen (150 kg/ha), but were at par with 125 kg N/ha. The low mean temperature during early growth period resulted in longer vegetative phase in late sown crop. However, higher values of mean minimum temperature during reproductive phase of normal and late sowing environment reduced the duration of reproductive phase as compared to early sown wheat crop.

Keywords: Wheat, Varieties, Sowing environments, Dry matter, LAI, CGR, Yield, Temperature

Wheat (*Triticum aestvium* L.) is the second most important cereal crop in the world after rice and is one of the major sources of energy, protein and fibre in human diet (Arya et al 2012) and so it occupies an important position in agricultural sector and overall financial system especially in the Asian region. Its wide spread cultivation is due to its adaptation to different agro climatic conditions. Wheat, a major cereal crop of the world being grown in about all the countries of the world across the 6 Continents and is the staple food crop of India; cultivated in about 30.56 m ha with production of 99.70 MTs (ICAR-IASRI 2019). Selection of improved varieties and optimum sowing time play a remarkable role in exploiting the yield potential of the crop under particular agro climatic condition. The accumulated temperature is also considered as the principal factor which affects the year-to-year variation in development of various phenophases (Gupta et al 2020). Advance or delay in sowing date, increasing N application and choice of suitable variety with the best thermal requirement represent the main agronomic manipulations which help to maintain existing crop production levels (Ventralla et al 2012, Gupta et al 2021). The unfavourable environments created by high temperature mostly during reproductive stages especially grain filling stage could be minimized by adjusting the sowing time to an optimum time for different varieties, which are suitable for early, normal and late sown environmental conditions for assured higher yield (Gupta et al 2020a). Current estimates indicated that wheat crop grown on around 13.5 m ha in India is affected by heat stress (Sareen et al 2012). It is also reported by the various researchers that the cool period for wheat crop in India is shrinking, while the threat of terminal heat stress is expanding (Gupta et al 2021, Gupta et al 2022a). Nitrogen is a key element for plant nutrition and other management practices which ultimately increases the yield of wheat crop (Cui et al 2010). High yielding new varieties can never be fully exploited with the existing fertilizer practice and thus fails to provide adequate yield. Since the information about the response of wheat varieties to sowing environments and N-levels under low altitude irrigated sub-tropical region of Jammu under lower Shivalik zone of Himalayas is lacking. To overcome these circumstances, an experiment was planned by selecting a set of recommended wheat varieties under different sowing environments with enhanced N-levels.

MATERIAL AND METHODS

Study site: Field experiments were conducted during *rabi* 2015-16 and 2016-17 at Research Farm of Agromet

Research Centre, SKUAST-Jammu (Latitude 32°39′ N, longitude 74°58′ E and altitude 332 m amsl).

Experimental details: Three wheat varieties HD 2967, RSP 561 and WH 1105 were sown under three sowing environments 25th October (early), 14th November (normal) and 4th December (late) with three nitrogen levels (100, 125 and 150 kg/ha) and replicated thrice. The experiment was conducted in split split plot design. Half of the nitrogen along with full dose of phosphorus and potassium was applied at the time of sowing as basal dose. The remaining half of nitrogen was top dressed in two equal splits, *i.e.* at CRI and before booting stage of the crop. The recommended dose of P and K was 50:25 kg/ha for wheat crop. However, nitrogen was applied as per the treatment combinations. The meteorological data, *viz*. maximum and minimum temperature for the *rabi* 2015-16 and 2016-17 were recorded at Agrometeorlogical Observatory of SKUAST-Jammu which is situated at about 50 m from the experimental site.

Growth parameters: For calculating dry matter accumulation the biomass of the plants cut near to the ground at different growth stages, sun-dried and thereafter kept in the oven for drying (65±5°C) till a constant weight obtained, thereafter dry matter calculated and expressed as g/m row length. From the biomass cut for dry matter accumulation, all the leaves were removed from these plants, counted and categorized into three groups of large, medium and small size. 2-3 representative leaves from each category were chosen and their area was measured with the help of leaf area meter (Leaf Area Software-Disha Info way). The leaf area was worked out by multiplying with the total number of leaves obtained category-wise and average leaf area/m^2 was worked out by further calculations. Leaf area index (LAI) was worked out.

$$\text{Leaf area index} = \frac{\text{Leaf area (m}^2\text{)}}{\text{Land area (m}^2\text{)}}$$

Specific leaf area was calculated as the ratio of leaf area (cm^2) to leaf dry mass (g) as per the formula (Yulin et al 2005):

$$\text{Specific leaf area (cm}^2\text{/g)} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry mass (g)}}$$

The crop growth rate (g/m^2/day) for each observational stage was calculated by substituting the corresponding dry matter accumulation value of these stages in the formula (Radford 1967) to calculate the crop growth rate

$$\text{CGR (g/m}^2\text{/day)} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where,

W_2=dry weight of crop plant at time interval T_2, W_1=dry weight of crop plant at time interval T_1

RESULTS AND DISCUSSION

Dry matter accumulation: Dry matter accumulation of wheat crop was significantly influenced by varieties, sowing environments and nitrogen levels at different intervals of time and continued to increase throughout the crop growing period up to the harvest (Table 1). At initial stages, the rate of dry matter accumulation was slow, which picked quickly with advancement in age of crop and again slowed down from 120 DAS onwards up to harvest signifying the typical pattern of sigmoid growth. Variety WH 1105 accumulated significantly higher dry matter followed by HD 2967. However, RSP 561 accumulated the lowest dry matter. Significant variation in dry matter accumulation in different wheat varieties might be due to their genetic variation (Prasad et al 2003, Jat and Singh 2004). Significantly superior higher dry matter accumulations were in wheat crop sown on 25th October followed by sowing environments 14th November and 4th December. Early sown crop got an advantage of favourable environmental conditions; might be higher fertilizer use efficiency which may have resulted in higher dry matter production in early sowing (Table 1). Delayed sowing reduced vegetative growth of the crop due to high temperature during the later stages which lead to lower dry matter production (Kaur et al 2010). The significantly higher dry matter accumulation observed by the crop when supplied by 150 kg N/ha which was statistically at par with 125 kg N/ha . However, dry matter obtained by 125 kg N/ha was significantly superior than at 100 kg/ha of N at all the stages. It might be due to increased cell division and cell expansion with the increased N availability (Kumar and Yadav 2005).

Specific leaf area: Specific leaf area (SLA) is an important index indicating the ratio of leaf area (cm^2) to leaf dry mass (g). Specific leaf area of wheat crop increased progressively with the advancement in crop age and a noticeable increase was observed between 60 and 90 DAS (Table 1). At various growth stages, specific leaf area recorded in WH 1105 variety were numerically higher than HD 2967 and RSP 561 varieties. As SLA is the leaf area per unit dry mass is an important trait in plant ecology as is associated with many critical aspects of plant growth and survival (Shipley and Vu 2002). Wheat crop sown on 25th October recorded higher specific leaf area followed by 14th November and 4th December sown crop (Table 1). Among the different N levels, numerically higher SLA recorded in 150 kg N/ha and was followed by the values recorded in 125 and 100 kg N/ha . The possible reason for the variation in SLA values might be ascribed to the fact that SLA values varied with the nutrients availability to the plants (Garnier et al 2001).

Crop growth rate: Crop growth rate (CGR) is an indicative of the pattern of rate of growth of crop plants during the growing period and it also determines the successive accumulation of dry matter at different periods of crop growth (Table 2). Wheat varieties at various growth stages showed non-significant differences with respect to CGR values except at 0-30 and 30-60 DAS. Crop growth rate of wheat varieties increased with the advancement in age of the crop and reached the peak values at 90-120 DAS; however, WH 1105 recorded numerically highest CGR at observations followed by HD

Table 1. Dry matter accumulation (g/m row length) and specific leaf area (cm^2/g) of wheat varieties as affected by various sowing environments and nitrogen levels

Treatments	Dry matter accumulation (g/m row length)					Specific leaf area (cm^2/g)				
	30 DAS	60 DAS	90 DAS	120 DAS	At Har	30 DAS	60 DAS	90 DAS	120 DAS	At Har
Varieties										
V_1: HD 2967	14.60	51.58	119.08	221.4	248.59	72.8	152.9	249.2	250.7	199.0
V_2: RSP 561	14.62	49.84	115.92	213.3	246.98	71.9	159.6	247.2	250.9	201.1
V_3; WH 1105	15.77	59.23	138.27	241.4	267.52	76.1	147.0	225.8	243.9	188.7
CD (p=0.05)	NS	7.03	17.09	16.87	13.88	NS	NS	NS	NS	NS
Sowing environments										
D_1: 25th October	16.97	61.32	143.14	246.90	282.64	88.4	161.3	226.7	238.2	178.2
D_2: 14th November	14.87	53.96	124.03	224.60	257.02	80.5	158.9	246.3	257.5	195.1
D_3: 04th December	13.15	45.37	106.10	204.60	223.43	51.9	139.2	249.1	249.9	215.3
CD (p=0.05)	1.2	6.87	9.38	8.97	8.65	NS	NS	NS	NS	NS
Nitrogen levels										
N_1: 100% RDN (100 kg N/ha)	14.00	49.96	118.02	214.70	240.37	72.8	152.1	240.4	246.5	197.6
N_2: 125% RDN (125 kg N/ha)	15.14	54.39	126.27	228.70	257.43	73.4	152.3	241.2	249.0	192.8
N_3: 150% RDN (150 kg N/ha)	15.84	56.31	128.97	232.60	265.28	74.6	155.1	240.6	250.0	198.3
CD (p=0.05)	0.97	3.85	7.06	7.84	6.37	NS	NS	NS	NS	NS

Table 2. Crop growth rate ($g/m^2/day$) and leaf area index of wheat varieties as affected by various sowing environments and nitrogen levels

Treatments	Crop growth rate ($g/m^2/day$)					Leaf area index				
	0-30 DAS	30-60 DAS	60-90 DAS	90-120 DAS	120 DAS At Har	30 DAS	60 DAS	90 DAS	120 DAS	At Har
Varieties										
V_1: HD 2967	2.14	5.42	9.90	15.00	3.98	0.35	2.04	4.12	3.40	2.37
V_2: RSP 561	2.14	5.17	8.69	14.30	4.95	0.33	1.97	4.03	3.33	2.33
V_3; WH 1105	2.32	6.37	11.59	15.10	3.84	0.38	2.23	4.33	3.66	2.58
CD (p=0.05)	0.17	0.65	NS	NS	NS	NS	0.17	0.18	0.20	0.17
Sowing environments										
D_1: 25th October	2.49	6.50	12.00	15.20	5.25	0.47	2.50	4.60	3.85	2.64
D_2: 14th November	2.18	5.73	10.28	14.80	4.75	0.38	2.18	4.23	3.58	2.47
D_3: 04th December	1.93	4.73	8.91	14.40	2.77	0.21	1.56	3.65	2.96	2.17
CD (p=0.05)	0.12	0.59	1.13	NS	1.68	0.04	0.12	0.16	0.17	0.11
Nitrogen levels										
N_1: 100% RDN (100 kg N/ha)	2.05	5.27	9.98	14.20	3.76	0.33	1.93	3.97	3.31	2.30
N_2: 125% RDN (125 kg N/ha)	2.22	5.76	10.54	15.00	4.22	0.36	2.12	4.21	3.51	2.46
N_3: 150% RDN (150 kg N/ha)	2.32	5.93	10.66	15.20	4.79	0.37	2.20	4.28	3.58	2.51
CD (p=0.05)	0.09	0.36	NS	NS	NS	NS	0.11	0.15	0.14	0.10

2967 and RSP 561. Alam et al (2013) also observed statistically similar crop growth rate among the different varieties. Statistically higher CGR values noticed in 25th October sown crop and followed by 14th November and 4th December sown wheat. Crop growth rate increased slowly at early stages of growth and reached the peak at about 90-120 DAS and thereafter, it declined. This was due to the maximum production of dry matter at early stages of plant growth at Jammu (Singh et al 2017). The periodic crop growth rate of wheat significantly influenced by different N levels at 0-30 and 30-60 DAS only and non-significant effects noticed during 60-90, 90-120 DAS and 120 DAS-at harvest. Significantly higher CGR was in 150 kg N/ha which were followed by statistically similar CGR at 125 kg N/ha and the lowest CGR in 100 kg N/ha. The fact behind these results might be that application of nitrogen resulted in increasing the proportion of protoplasm of cell wall material which caused an increase in the size of cell, which ultimately increased the growth parametres like dry matter accumulation (Alam 2013).

Leaf area index: Statistically higher leaf area index (LAI) values recorded in WH 1105 which was followed by HD 2967 and RSP 561 at all the growth stages (Table 2). However, the values of LAI at 30 DAS were unable to show any significant difference. The difference in LAI among the varieties may be referred to inherent difference between the varieties for LAI, number of leaves per plant and their tillering capacity during the growing seasons (Jatti 2013). Among the sowing environments, significantly lower LAI observed in 4th December sown crop and higher values were observed in 25th October sown wheat in all the periodic observations of LAI from 30 DAS to harvest. However, LAI decreased gradually after 90 DAS in all the sowing environments under study. The lower values of LAI in 4th December sown wheat might be due to curtailment of 20 days most active growth period on account of late sowing (Singh et al 2003). At the various growth stages, N levels affected leaf area index significantly. Statistically notable augmentation in leaf area index was in 150 kg N/ha at various time intervals. However, the wheat crop supplied with 125 kg N/ha recorded LAI values statistically similar to 150 kg/ha of nitrogen, which was followed by 100 kg N/ha at all the growth stages. Patra and Ray (2018) observed significant LAI values of wheat with an increase in N levels from 120 to 150 kg/ha.

Yield: Grain yield of wheat was significantly influenced by varieties, sowing environments and nitrogen levels in both the crop growing seasons and second year crop marked an improvement in grain yield over that of first year (Table 3). Among the varieties, WH 1105 recorded significantly superior grain yield as compared to the other two varieties. However, varieties HD 2967 and RSP 561 were statistically similar during both the years of experimentation. Similar trend was noticed for straw and biological yield of wheat crop. The higher grain, straw and biological yields of wheat could be attributed to greater genetic potential with efficient utilization of radiation by leading to production of maximum

Table 3. Performance of different wheat varieties as affected by various sowing environments and nitrogen levels

Treatments	Grain yield (kg/ha)		Straw yield (kg/ha)		Biological yield		Harvest index (%)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Varieties								
V_1: HD 2967	4160	4395	5858	6378	10017	10773	41.5	40.8
V_2: RSP 561	3975	4255	5923	6488	9898	10743	40.2	39.6
V_3: WH 1105	4573	4617	6271	6748	10844	11365	42.1	40.5
CD (p=0.05)	332	184	329	281	501	338	NS	NS
Sowing environments								
D_1: 25th October	4707	4857	6614	7272	11321	12130	41.5	40.0
D_2: 14th November	4313	4649	5959	6696	10272	11346	42.0	41.0
D_3: 04th December	3687	3759	5479	5645	9166	9405	40.3	40.0
CD (p=0.05)	202	182	258	254	345	397	1.36	0.78
Nitrogen levels								
N_1: 100 % RDN (100 kg N/ha)	3955	4179	5652	6263	9607	10441	41.1	40.0
N_2: 125 % RDN (125 kg N/ha)	4313	4471	6103	6605	10416	11076	41.3	40.4
N_3: 150 % RDN (150 kg N/ha)	4440	4616	6297	6747	10737	11363	41.3	40.6
CD (p=0.05)	135	141	201	156	248	259	NS	NS

leaf area and dry matter which in turn results into higher yields. Similar results were also reported by Jatti (2013) and Gupta et al (2022). Variety WH 1105 performed significantly superior to HD 2967 at various locations as reported in the report of AICWBIP (Tiwari et al 2015-16). Grain yield of wheat crop was affected to a great extent due to different sowing environments. Delayed sowing adversely affected the yield of wheat crop. Significant higher grain yield was observed in early sown conditions (25th October) and followed by statistically lower values registered with normal and late sowings in both *rabi* 2015-16 and 2016-17. These two latter sowing environments also differed statistically significant from each other. Normal and late sown wheat recorded about 9.1 and 27.6% less grain yield than early sown crop. Similar trend was noticed for straw and biological yield of wheat crop. The possible reason behind the significant higher yield values in early sowing might be the availability of optimum environmental conditions for growth and development of crop which could have enhanced accumulation of photosynthates from source to sink and thus resulted in higher yield values (Ram et al 2012; Gupta et al 2021a). Wheat crop when applied 150% RN (150 kg/ha) performed outstanding with respect to grain yields in both years of experimentation but the values were at par with that of 125% RN (125 kg/ha). Recommended dose of nitrogen (100 kg/ha) also performed well but the values were significantly inferior to other two doses of nitrogen. Similar trend was noticed for straw and biological yields of wheat crop. Higher wheat yield in enhanced N levels (125 kg/ha) could be traced to adequately N fertilized crop benefitted from higher rates of N nutrition that might have resulted into more vigorous and extensive root system of crop leading to increased vegetative growth means for more sink formation and greater sink size, greater carbohydrate translocation from vegetative growth (Hameed et al 2003).

From the data, it can be inferred that among the wheat varieties, the values of harvest index were statistically non-significant. However, sowing environments had a significant effect on harvest index values of wheat crop. Wheat crop sown on 14th November recorded higher values of harvest index but were statistically similar to earlier sown wheat. Different N levels also had non-significant effect on harvest index of wheat crop. However, numerically higher values of harvest index observed in 150 kg N/ha which was followed by the values recorded in 125 and 100 kg N/ha in the years 2015-16 and 2016-17. Decline in HI in later sowings as compared to early sowing might be due to higher temperature during reproductive stages in normal and late sowings (Dhyani 2010). The interaction effect of different varieties of wheat with N levels was significant during both seasons of experimentation (Fig. 1a). All the three varieties responded well to the enhanced nitrogen levels. Significant increment in grain yield was observed with an increase in N level from 100 to 125 kg/ha only; but thereafter increase in grain yield due to enhanced level of nitrogen was not significant. However, higher pace of response to increased dose of nitrogen with respect to grain yield was in WH 1105 followed by RSP 561 and HD 2967. Kaur et al (2016) also observed that different genotype varies widely in their yield response under different N management. Various sowing environments also interacted with N levels significantly for grain yield of wheat (Fig. 1b). Early sowing of wheat crop responded significantly to enhanced dose of nitrogen up to 150 kg/ha. Whereas, in case of normal sowing, significant response to nitrogen level was noted up to 125 kg/ha after that the increase in grain yield of wheat crop was not significant. However, crop sown on 4th December, responded significantly only up to 100 kg N/ha, on further enhancement of nitrogen dose, the grain yield of wheat crop did not increased significantly under late sown conditions. Dagesh et al (2014) observed a significant difference for interaction effects of nitrogen and sowing environments in wheat crop yield.

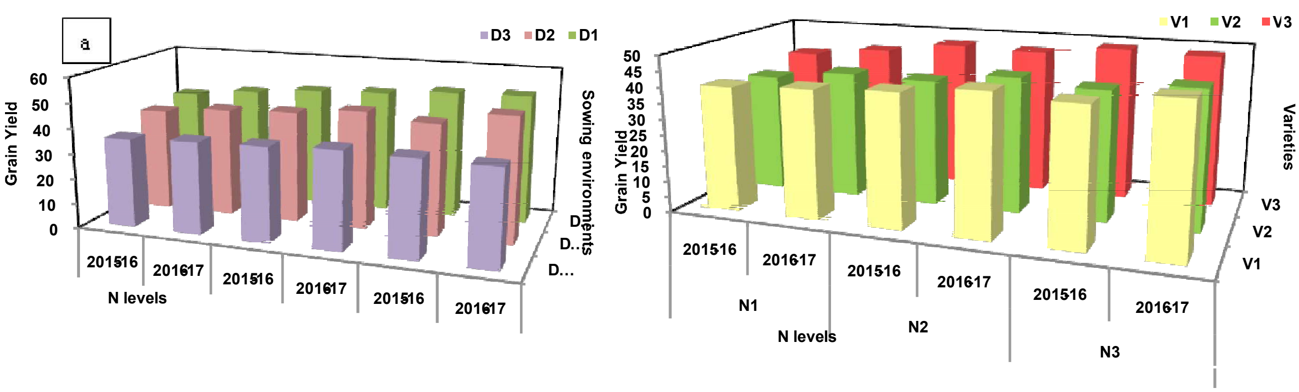

Fig. 1. Interaction effect of (a) N levels and sowing environments and (b) N levels and varieties on grain yield of wheat during *rabi* 2015-16 and 2016-17

Table 4. Effect of sowing environments on vegetative and reproductive period of wheat in relation to mean temperature

Sowing environments	Vegetative stage		Reproductive stage	
	Days taken	Mean T_{min}	Days taken	Mean T_{min}
D_1: 25th October	59	9.2	103	8.6
D_2: 14th November	65	6.5	85	10.1
D_3: 4th December	70	6.0	69	12.3

Weather studies; Days taken from sowing to attain various phenophases (vegetative phase) increased with delay in sowing. However, total crop duration decreased with delay in sowing, thereby decreasing the length of crop growing period (Table 4). The crop sown earlier (25th October) required more days (162) to attain physiological maturity as compared to normal (14th November) and late (4th December) sowings. The delay in sowing decreased the number of days required for maturity. The reproductive period of earlier sown wheat crop was longer (103 days) as compared to other two sowing environments *i.e.* 85 and 69 days under normal and late sowings, respectively. Thus, the reproductive period reduced significantly with delay in sowing by 18 and 34 days when the sowing was delayed by 20 and 40 days from earlier sowing environment (25th October), respectively. The low mean temperature during early growth period resulted in longer vegetative phase in late sown crop. However, higher values of mean minimum temperature during reproductive phase of normal and late sowing environment reduced the duration of reproductive phase as compared to early sown wheat crop. The similar findings were also reported by Gupta et al (2017). Khushu et al (2008) also reported that higher temperature during reproductive phase reduced the duration of late-sown *Brassica* crop.

CONCLUSION

Wheat variety WH 1105 recorded significantly higher growth parameters, yield and yield attributes over HD 2967 and RSP 561. Among sowing environments, 25th October sown wheat crop registered significantly higher values of all the yield attributing characters, grain and straw yield followed by normal and late sowing environments. The application of 150 kg N/ha recorded significantly higher yield attributes and yield of wheat crop as compared to the other N levels *viz* 125 and 100 kg/ha, but the values recorded in 125 kg N/ha remained at par with that of 150 kg N/ha. Among the interaction effects, higher wheat grain yield was obtained by sowing WH 1105 on 25th October and 14th November. Under late sown conditions, all the three varieties showed similar yield. However, variety RSP 561 performed similarly during early and normal sowing environments.

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Assessment of Available Major and Micronutrient Status of Soils under Varied Cropping Systems of N.T.R district, Andhra Pradesh

P.N. Siva Prasad, P. Venkata Subbaiah, N. Rajasekhar, I. Venkata Reddy and M. Rajanarasimha

Dr. K.L. Rao Krishi Vigyan Kendra, Garikapadu, Jaggaiahpeta
Acharya N.G. Ranga Agricultural University, Guntur-521 175, India
E-mail: sivassac007@gmail.com

Abstract: Assessment of soil properties and nutrient status is essential for addressing issues of soil health through which one can guide for maintaining sustainable crop productivity. In view of this, soil samples were collected from selected villages under different mandals of NTR district to assess physico chemical properties, macronutrients and micro nutrients status. A total of 144 soil samples (0-20 cm depth) were collected from Rice-Rice, Rice-Pulse, Cotton-Pulse, Maize-Pulse and agri-horticulture cropping systems and results revealed that the soils under investigation were slightly acidic to alkaline in reaction (pH 6.60 to 8.20), mostly non-saline and low too high in organic carbon status (0.18 to 1.52 %). The mean available nitrogen, phosphorus, potassium and sulphur content recorded were 298, 22.90, 196 and 45 kg^{-1} ha Exchangeable Ca, Mg in the ranged from 1.90-10.20 and 1.20-5.50 C mol (p+) kg^{-1}. With respect to micronutrients, the mean available Zn, Mn, Cu, Fe and B content are 0.52, 3.50, 1.52, 5.50 and 0.85 mg kg^{-1} respectively. The nutrient index (NI) of studied samples for organic carbon (1.54), nitrogen (1.30) is categorized under low, sulphur (2.86) and magnesium (2.82) are categorized as high and K, Ca and micronutrients as medium.

Keywords: Fertility status, Nutrient Index, Correlation, Major, Secondary and micronutrients

Soil testing is often used to determine the available nutrient status and nutrient supplying power of soil which helps in developing cost effective nutrient management practices that serve as a basis for amendments and sound fertilizer recommendations, which in turn leads to sustainable long term agriculture production by way of adoption of good agronomic management practices by farmers in the study area (Subbaiah et al 2022). Macronutrients (N, P, K, S) and micronutrients (Zn, Fe, Cu, Mn and B) are very important soil elements that determine crop yields in general and physicochemical properties like pH, EC, Organic Carbon in particular under normal environmental conditions. Soil fertility is one of the important factors controlling crop yields and soil characterization in relation to evaluation of soil fertility of an area or a region is an important aspect in the text of sustainable production (Prasad et al 2020b). In present context, maintaining soil fertility is a key problem in Indian agriculture, especially under the country's rapidly growing population in recent decades. Erratic rainfall, minimal recycling of farm residues including livestock waste, non-adoption of soil and water conservation measures, continuous cultivation of exhaustive crops and imbalanced fertilizer application are some of the major causes of soil degradation in India. Soil is one of the most important natural resources for plant growth that deteriorates from its original status due to the imbalance fertilizer application, faulty management practices, incorrect crop rotation, excess or scanty irrigation and adverse climate conditions, thereby decreasing productivity of rice, pulses, wheat, mustard, maize and sugarcane. The decrease in soil productivity may be attributed to poor physical properties, low organic carbon content, buildup of salts leading to soil salinity/alkalinity, imbalanced fertilizer application and multi nutrient deficiencies. The presence of more salt in the rooting zone may have a germination effect or may be essential for crop development. The quantity of fertilizer supplementation is determined by knowing crop nutrition demand and nutrient supplying power of the soil. The improper nutrient management led to emergence of multinutrient deficiencies in the Indian soils. Without maintaining soil fertility, it is hard to enhance agricultural production and feed the alarmingly increasing population. In the last few decades, soil analysis and study of micronutrients level has become an important topic of research. Information on the available nutrient status of soils is a pre requisite for advising individual farmers on fertilizer scheduling and to monitor changes in soil fertility over a period. The available nutrients *viz.,* nitrogen, phosphorus, potassium, sulphur, iron, manganese, zinc and copper controls fertility and productivity of a particular soil. Land use induced changes in soil properties are essential for addressing the issue of agro eco system transformation and sustainable land productivity (Subbaiah and Rajasri 2020, Wani et al 2022). In NTR district, rice is cultivated under different irrigation sources like canal command, tank fed, lift irrigation schemes and filter points to an extent of 3 lakh hectares. Soil nutrient status of any cultivable soil is the primary indicator of productivity.

MATERIAL AND METHODS

The study area was situated in between Latitude 16° 86' N and 17° 14' N Longitude 15° 71' E and 16° 47' of E located in NTR district of Andhra Pradesh bordered with Krishna district and Eluru districts on the East, Palnadu district and Guntur districts on the South, Suryapet district of Telangana state on the West, Khammam district of Telangana state on the North and river Krishna flows towards East and acts as border between NTR and Palnadu. Surface (0-20 cm) soils are collected from different areas of NTR district, Andhra Pradesh. All together a total of 174 soil samples were collected from farmer's fields. The samples were air-dried, ground and passed through a 2 mm sieve for analysis of physicochemical, chemical properties and micronutrient content of soil. The pH and EC of the soils was determined in 1:2.5 soil water suspension using a glass electrode pH meter and EC meter as described by Jackson 1973. The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon (SOC) content. During the delineation of the study 174 surface soil samples of different cropping systems were collected and the details are presented in Table 1. Collected samples were analyzed for pH, EC, organic carbon and available macro and micronutrients using standard protocols (Jackson, 1973). The available zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn) in soil samples were estimated by atomic absorption spectrophotometer following DTPA extraction method (Lindsay and Norvell 1978). The deficiency and sufficiency areas were then delineated based on the critical limit given for Fe, Mn, Zn, Cu. Available boron was estimated by using Azomethine-H method. Soil test rating of available nutrients of standard protocol (Table 2) or critical limits of micronutrients will distinguish deficiency from sufficiency which could be employed to advice on need of fertilization (Sivaprasad et al 2022).

Table 1. Categories of soil samples of NTR district of Andhra Pradesh

Soils supporting crop	No of samples	% of total samples
Paddy	80	45.98
Maize	23	13.22
Cotton	17	9.77
Red gram/Bengal gram	27	15.52
Chilies	10	5.75
Tomato and other vegetables	12	6.89
Miscellaneous crops including surface samples of orchards	5	2.87
Grand total	174	100

Nutrient Index (NI)

Nutrients index (NI) was enumerated for surface soil samples as described by Motsara et al 1982.

$$\text{Nutrient Index (N.I)} = \frac{(Nl \times 1) + Nm \times 2 + Nh \times 3)}{(Nt)} \times 100$$

where,

Nt= total number of samples analyzed for a nutrient in given area

Nl= number of samples falling in the low category of nutrient status

Nm = number of samples falling in the medium category of nutrient status

Nh= number of samples falling in high category of nutrient status

The index values are rated into various fertility categories *viz*., low (<1.67), medium (1.67-2.33) and high (>2.33) for available N, P and K.

The correlation analysis of data was computed in relation to available micronutrients content with different physicochemical properties of the soils with SPSS Software and MS Excel.

RESULTS AND DISCUSSION

The pH of soil samples analyzed in the district ranged from 6.60-8.20. Thus, the soils of the district were categorized into acidic, neutral and alkaline. Higher values of pH in crop lands are due to release of bases and their deposition over a long period. These results are in conformity with the findings made by Altaf and Subbarayappa (2022). The electrical conductivity of analyzed soil samples were between 0.08-2.10 dS m^{-1} with a mean and median of 0.86 and 0.95 dS m^{-1}. It was observed that only ten per cent soils register EC more than 1 dS m^{-1} and EC of district soils is suitable for growing different types of crops. The organic carbon content of district soils was in the range of 0.18 to 1.52 %. The mean and median of organic carbon content in the studied soils was 0.56 and 0.61, respectively. Out of 174 soil samples of the district, 56 % were low in organic carbon content, 34 % were medium whereas only 10 % were with high in organic matter content. Low organic carbon in the soils of NTR district may be due to meager application of organic manuresa and may be due to rapid rate of decomposition because of continuous manipulation of surface soil due to intensive cultivation at every cropping season coupled with high soil temperature prevailing in the district. Similar reports are made by Prasad et al (2020b) and Altaf and Subarea (2022). The high content of organic carbon reported in the studied area might be due to addition of organic matter and its subsequent decomposition. These results are in confirmatory with Sathish et al (2017) and Subbaiah et al (2022).

Major and secondary nutrient status: The available nitrogen content ranged from 131.00 to 328.00 kg ha^{-1} with a mean and median of 298.00 and 312.00 kg ha^{-1}, respectively (Table 4). The soils contained low to medium nitrogen content. The low available nitrogen in most of the soils might be due to the higher temperature that might have increased volatilization loss of nitrogen. Rajeshwar et al (2009) and Subbaiah (2020) also observed similar trend in the soils of Krishna district, Andhra Pradesh.

The available phosphorus content ranged from 9.80 to 117.00 kg ha^{-1} with a mean and median of 22.90 and 20.20 kg ha^{-1}, respectively. The phosphorus content of the soils ranged from low to high. Phosphorus is present in soil as solid phase with varying degree of solubility. When water soluble P is added to the soil, it is converted very quickly to insoluble solid phase by reacting with soil constituents. These reactions affect the availability of P and as a result of these reactions, a very small amount of total P is present in soil solution at any time reflected by soil testing. High and continuous application of phosphatic fertilizers might have resulted in occurrence of high phosphorus soils in the district. Such build up in available phosphorus was also noticed in the soils of Kolar district (Prasad et al 2020b)

The available potassium ranged from 121.67 to 359.00 kg ha^{-1} with mean and median of 196.00 and 210.00 kg ha^{-1}, respectively. The potassium status ranges from low to high. Low potassium levels in soils are due to leaching and lessivage of this element to lower layers which lead to loss of K (Wani et al 2022) and in addition to this in majority areas there is no external soil application of K due to misconception that soils are rich in K. These results confirmed the findings of Prasad et al (2020b) in Kolar district of Karnataka. Adequate available K in these soils may be attributed to the prevalence of potassium rich minerals like Illite and Feldspars (Sharma et al 2008 and Sharma et al 2013). The variation in available potassium across the soils of different districts was noticed by several workers and was attributed to variation in mineralogical compositions. These reports are similar to the findings of Reza et al 2012. The available sulphur ranged from 5.00 to 180.00 kg ha^{-1} with mean and median of 45.00 and 59.00kg ha^{-1}, respectively. The sulphur content in the studied areas ranges from low to high. The exchangeable calcium ranges from 1.90 to 10.20c mol (p^{+}) kg^{-1} with mean

Table 3. Analytical values and percent distribution of Physico-chemical properties of soils

Parameter	pH	E.C (dS m^{-1})	O.C (%)
Range	6.60-8.20	0.08-2.10	0.18-1.52
Mean	7.59	0.86	0.56
Median	7.41	0.95	0.61
Low samples (%)	15 (Acidic)	68 (Normal)	56.00
Medium samples (%)	40 (Neutral)	22 (Non-saline)	34.00
High samples (%)	45 (Alkaline)	10 (Saline)	10.00

Table 2. Soil test rating of primary, secondary and cationic micronutrients of study area

Nutrients	Units	Soil testing rating		
		Low	Medium	High
Organic carbon	Percent	0.5	0.5-0.75	>0.75
Available N	Kg^{-1} ha	<280	280-560	>560
Available P_2O_5		< 23	23-56	> 56
Available K_2O		< 140	140-330	> 330
Available S		< 22.4	22.4 - 44.8	> 44.8
Exchangeable Ca	M.eq 100 g^{-1}	< 1.5		> 1.5
Exchangeable Mg		< 1		> 1
DTPA-extractable Fe	Mg kg^{-1}	<5.5	5.5-9.5	>9.5
DTPA-extractable Cu		<0.4	0.4-0.8	>0.8
DTPA-extractable Mn		<4.0	4.0-8.0	>8.0
DTPA-extractable Zn		<0.6	0.6-1.2	>1.2
Available boron		< 0.5	0.5- 1	> 1
Nutrient Index		<1.67	1.67 to 2.33	>2.33

and median of 4.20 and 3.90c mol (p^+) kg^{-1} soil. The exchangeable magnesium ranges from 1.20 to 5.50 with mean and median of 2.80 and 2.61c mol (p^+) kg^{-1} soil. All the soils were in the sufficiency range of Mg may be due to its genesis in the semiarid area.

Availability of micro nutrients: Available Zn content in soils of NTR district ranged from 0.18 to 2.96 mg kg^{-1} with mean and median of 0 .52 and 0.61 mg kg^{-1}, respectively. The soils of the district were low to high in zinc category. The Fe content ranged from 4.25 to 12.60 mg kg^{-1} with mean and median of 5.50 and 5.45 mg kg^{-1}, respectively. The soils were in low to high category. This might be due to its topography and amount of iron required by crops is being released by iron bearing minerals as many iron ores are existing in district. Similar trend of Fe was reported by Prasad et al (2020a) in soils of Chikkaballapura district of Karnataka.

The Mn status of district ranged from 2.25 to 9.45 mg kg^{-1}, respectively with mean and median of 3.50 and 3.16 mg kg^{-1}. The Mn content in soils was low to high. The Cu status ranged from 0.46 to 6.92 mg kg^{-1} with mean and median 1.52 and 1.64 mg kg^{-1}, respectively. The soils of the district were low to high in copper status and might be due to interactive effect of soil properties like pH, EC and OC which have managing role in the availability of Cu. The boron status of district ranged from 0.01to 5.29 mg kg^{-1} with mean and median of 0.85 and 0.71 mg kg^{-1}, respectively. The soils of the district were low to high in boron status.

Nutrient index: Considering the concept of soil nutrient Index, the soils of the studied area were grouped into three categories as low, medium and high index values (Table 5). The nutrient index (NI) of NTR district reveals that organic carbon (1.54) and available nitrogen (1.30) were categorized as low, available phosphorus (2.30), potassium (1.79), calcium (1.87), zinc (2.02), copper (2.05), iron (2.30) and boron (1.85) are categorized under medium, whereas exchangeable magnesium (2.82) and sulphur (2.86) was

Table 4. Available macro, secondary and micronutrient status of soils in diversified areas of NTR district

Parameter	Units	Range	Mean	Median
Available nitrogen	kg ha^{-1}	131.00 - 328.00	298.00	312.00
Available phosphorus		9.80 - 117.00	22.90	20.20
Available potassium		121.67- 359.00	196.00	210.00
Available sulphur		5.00 - 180.00	45.00	59.00
Exchangeable calcium	c mol (p^+) kg^{-1}	1.90 - 10.20	4.20	3.90
Exchangeable magnesium		1.20 - 5.50	2.80	2.61
Available zinc	mg kg^{-1}	0.18 - 2.96	0.52	0.61
Available manganese		2.25 - 9.45	3.50	3.16
Available copper		0.46 - 6.92	1.52	1.64
Available iron		4.25 - 12.60	5.50	5.45
Available boron		0.01 - 5.29	0.85	0.71

Table 5. Nutrient Index (NI) of studied soils of NTR district

Parameter	Low	Medium	High	N.I	N.I. Class
Organic carbon	81	49	14	1.54	Low
Available nitrogen	109	26	9	1.30	Low
Available phosphorous	20	60	63	2.30	Medium
Available potassium	59	56	29	1.79	Medium
Exchangeable calcium	33	96	14	1.87	Medium
Exchangeable magnesium	35	0	124	2.82	High
Available sulphur	32	0	127	2.86	High
Available zinc	43	55	46	2.02	Medium
Available manganese	22	79	43	2.15	Medium
Available copper	29	79	36	2.05	Medium
Available iron	14	72	58	2.30	Medium
Available boron	50	65	29	1.85	Medium

under high nutrient index category. Low content of soil nitrogen in different cropping systems is possibly due to recurrent tillage operations that causes quick mineralization of soil organic matter and organic N and transforms them into mineral N which is lost as gaseous nitrogen to the atmosphere and is from the soils. These results are similar to the findings of Wani et al (2022). For macronutrients these results are in conformity with the findings of Verma et al (2016) for soils of Punjab. For micronutrients the results are in conformity with the findings of Kumar et al (2017) and Prasad et al (2020[a]) at Jhabua district of Madhya Pradesh and Chikkaballapura district of Karnataka. This shows that majority of the studied soils are showing depletion of nutrients status which may be due to continuous cropping without application of balanced levels of manures and fertilizers to soils. The details regarding percent distribution of chemical properties of studied area of NTR district with categories are clearly depicted in Figure. 1.

Correlation study: Among the soil properties, soil pH and organic carbon has been identified as the most important soil factors controlling nutrient supplying power and the availability of nutrients in soil (Altaf et al 2022).In general, pH shows significant correlation with nutrients like macro and micronutrients (Table 6). There were significant and positive correlations between pH and Ca and Mg. Negative, significant correlation was between pH and N, P and S. Similarly, a significant and negative correlation was found between EC and N, P and S while significant and positive correlation was found with Ca and Mg. The organic carbon showed positive significant correlation with N and P. Organic carbon is positively correlated with P showing that organic matter tends to reduce P fixing capacity of soil by replacing phosphate ions by humate ions and forms protective humus coating on sesquioxide particles and decomposition of organic matter also releases acids that increase solubility of calcium phosphates besides forming humic-phosphor complexes (Wani et al 2022). The Zn availability is positively and significantly correlated with pH, EC and organic carbon. The influence of Organic carbon is more pronounced as seen from highest coefficient of correlation of organic carbon with Zn (Table 7). The Zn availability increased with increase in organic carbon content of soil and decrease in Zn availability with increase in pH but there was a tremendous increase in availability of Zn with increasing OC content from 0.5to0.75% followed by pH. At the same time, it can be inferred that uptake of Zn by plants is not merely a function of pH but it is controlled by other physiological factors and associated

Table 6. Relationship between available macronutrients and physicochemical properties of representative samples of study area

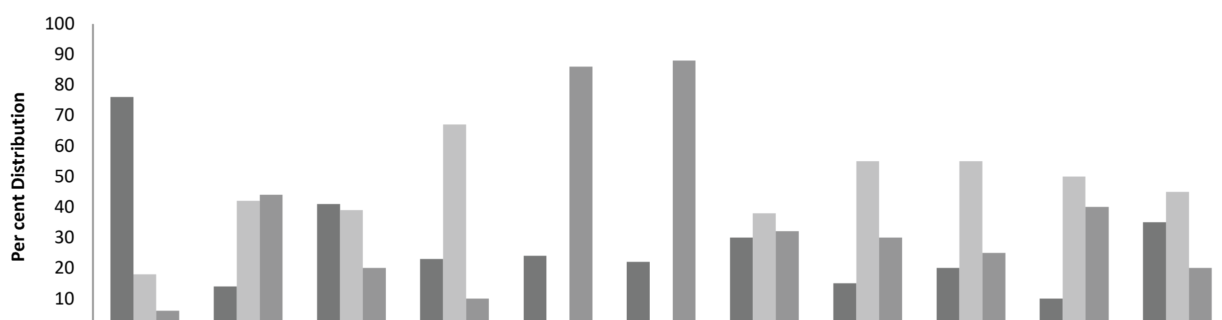
Available nutrient	pH	EC	OC
Nitrogen	-0.342**	-0.326**	0.285*
Phosphorus	-0.194*	-0.270*	0.538**
Potassium	-0.177	-0.135	0.099
Calcium	0.568**	0.538**	0.253
Magnesium	0.502**	0.426**	-0.132
Sulphur	-0.606**	-0.603**	0.167

Correlation is significant @ 0.05% **Correlation is significant @ 0.01%

Table 7. Relationship between available micro nutrients and physicochemical properties of representative samples of study area

Soil properties	Zn	Fe	Cu	Mn
pH	0.491*	NS	NS	-0.453*
EC	0.435*	0.437*	NS	NS
OC	0.636**	0.480*	0.628**	-0.438*

Correlation is significant @ 0.05% **Correlation is significant @ 0.01%



	Available Nitrogen	Available Phosphorus	Available Potassium	Available Sulphur	Exchangeable Calcium	Exchangeable Magnesium	Available Zinc	Available Manganese	Available Copper	Available Iron	Available Boron
Low (%)	76	14	41	23	24	22	30	15	20	10	35
Medium (%)	18	42	39	67			38	55	55	50	45
High (%)	6	44	20	10	86	88	32	30	25	40	20

Fig. 1. Percent distribution of chemical properties of studied soils

nutrients. Soil pH did not have a consistent effect on DTPA extractable Fe content of soils. However, organic carbon had influence on the DTPA-Fe content of soils. The results find support from positive and significant coefficient of correlation of DTPA-Fe with Organic carbon. A positive and significant correlation was obtained between DTPA-Fe with EC. Statistically there was no relationship of DTPA-Cu with pH but increasing Organic carbon content had a prominent effect on Cu availability as it is evident from a highly significant coefficient of correlatio) between Organic carbon and DTPA extractable Cu. It may be because complexing agents are generated by organic matter which in turn promoted Cu availability in soils. The availability of Mn decreased with increase in pH (Frierch and Catalano 2012). The DTPA-Mn of the soil was negatively correlated with OC and the availability of Mn decreased with increase in OC content.

CONCLUSION

The nutrient index (NI) of studied areas of NTR district revealed that in majority of samples N P, K, S and micronutrients are moderately sufficient to deficient. Based on the status of nutrients analyzed through soil testing, fertilizer recommendations must be made which helps in maintaining soil health which in turn improves availability of nutrients to crops for better growth and yield enhancement in sustained manner. Without soil testing, under or excess application of chemical fertilizers render agricultural soils towards degradation under long run and further lead to drastic reduction in the productivity of crops.

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Brassica juncea L. based Diversification Approaches and Operational Practices for Productivity and Economics under Eastern Zone of Haryana

Munish Leharwan, Yogesh Kumar, Rakesh Kumar, Pankaj Kumar Saraswat, Raj Kumar, Arun Kumar T.V. and Ankush Kumar[1]

Krishi Vigyan Kendra, ICAR-National Dairy Research Institutes, Karnal-132 001, India
[1]Department of Plant Pathology, CCSHAU, Hisar-125 004, India
E-mail: munishleharwan7@gmail.com

Abstract: Cluster frontline demonstrations technology for production potential of latest improved technology of mustard crop covering 205.68 ha area were carried out by Krishi Vigyan Kendra at 354 farmers' fields in Karnal district of Haryana during five consecutive *Rabi* seasons 2017-18 to 2021-22. The critical inputs were identified in improved production technology through Participatory Rural Appraisal (PRA) of adopted villages. Traditional farmers' practices were treated as control treatment for comparison with recommended practices treatments. The average yield of mustard under latest improved technology ranged from 16.0 to 21.50 q/ha as compared to 12.30 to 16.00 q/ha under farmers practice. The maximum seed yield (21.50 q/ha) was in 2018-19, and was 34.37 per cent more over the farmers practice. The average yield registered 29.09 percent higher over the farmers practice. The average of technology gap, extension gap and technology index were found to be 11.21 q /ha, 4.09 q/ha and 36.85 per cent respectively. The perceived technical gap may be due to differences in crop management practices, soil fertility and agro-climatic situation of Karnal district. The extension gap suggested the need to aware the farmers through various extension system for the adoption of latest improved technologies. Average net profitability was Rs. 53709/ha as compared with farmers practices (Rs. 37527/ha) and average benefit cost ratio i.e., 3.13 and 2.58 in demonstrated field and farmers practice respectively.

Keywords: Chickpea, CFLD, Extension and technology gap, B:C ratio

Indian mustard (*Brassica juncea* l.) is one of the major *Rabi* oilseed crops of India; Mustard is cultivated in Canada, China, Australia, Germany, France, Poland and Pakistan. In India, it is the second largest mustard growing countries in the world and ranks 3rd among the major mustard producer countries (Bharat et al 2022). The area, production, and productivity of mustard in India is 6.78 million ha, 9.12 million tons and 1345 kg per ha respectively (DES 2021). The mustard occupies the highest productivity in Haryana 2058 kg per hectare and is grown in an area of 0.61 million ha with production 1.25 million tones. In the production and productivity of mustard is mainly influenced by climatic condition, water and fertilizers management and soil physical properties. Mustard grown well under irrigated/rainfed situations. The temperature required for seed germination is 25°C and grow well in low temperature. The sandy to heavy clay soil is good for mustard (Pal et al 2017). Among the commonly applied fertilizers nitrogen and sulphur is the major element in mustard productivity as these are essential for synthesis of amino acids, protein, oil, activates enzymes and component of Vit-A. among these Sulphur are the sources of pungency in oilseeds (Dubey et al 2022). Inspite the high value and quality of oil in mustard crop and adaptability in various agro-climatic conditions, the area, production and productivity of mustard have been up and down due to various abiotic and biotic stress and limited use of improved technological intervention to-gather with domestic price support programme is the major reason for low area and production in the district. In present frontline demonstrations were organized in participatory mode with the aim to increase production potential of mustard crop at the farmers' field under different cluster of districts Karnal.

MATERIAL AND METHODS

Cluster Frontline demonstrations of Mustard were carried out by KVK Karnal (Haryana) during *Rabi* season 2017-18 to 2021-22. The CFLD were conducted in village using the participatory approach where farmers are engaged it all level. The total rainfall received during the experimental seasons was 70.2 mm in 2017-18, 71.8 mm in 2018-19, 303.1 mm in 2019-20, 124.2 in 2020-21 and 191.2 mm in 2021-22 respectively, respectively (Fig. 1).

The technology to be demonstrated for mustard was identified based on Participatory Rural Appraisal technique. The control fields were maintained by the farmers with their own cultivated practices. KVK Karnal provide critical input such as improved variety seed, soil ameliorates, Bio-fertilizers, integrated diseases and insects control. Under FLD programme 0.4 ha area is allotted under demonstration at farmer's field and adjacent 0.4 ha was used farmers field advised to use improved package of practices of mustard crop recommended for district Karnal. KVK scientist regularly visited the demonstration fields for proper guidance and interaction to the farmers. During the course demonstration, group meeting, skill training, field visit, field day and Kisan gosthties were regularly conducted for creating mass awareness about the technology demonstrated. The fact sheet also been provided to each participatory farmers to record all the data regarding development of crop. During the period a total 354 Demonstrations were conducted in 205.68 area of district Karnal. The major mustard varieties demonstrated under period are showed in (Table 1). Data were collected from both the demonstration as well as farmers field. Yield from the demonstration and farmer's field were obtained using crop cutting technique and analyzed statically. The technology gap, extension gap and technology index were calculated using the following formula by (Kumar 2014a). Other parameters such as gross return, net return, cost of cultivation and benefit-cost ration were also calculated as per (Leharwan et al 2021)

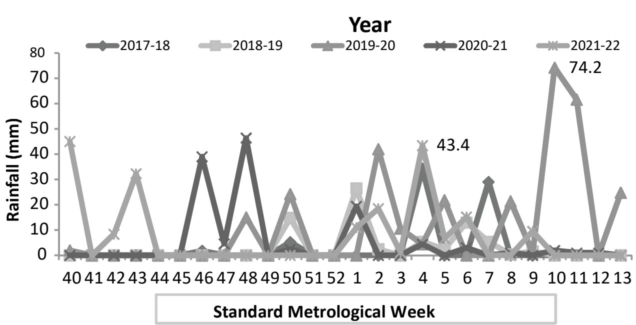

Fig. 1. Average weekly rainfall (RF), during the experimental seasons (October to March)

Technology Gap = Potential yield (Kg/ha) - Yield of improved technology (Kg/ha)

Extension Gap = Yield of improved technology (Kg/ha) - yield under farmer practices (Kg/hg)

$$\text{Technology Index} = \frac{\text{Potential yield} - \text{Yield of improved technology}}{\text{Potential yield}} \times 100$$

Additional cost (Rs/ha) = Improved technology cost-Farmer practice cost

Additional return (Rs/ha) = improved technology return - Farmer Practice return

Effective gains = Additional return – Additional cost

RESULTS AND DISCUSSION

Adopted farmers are dependent on the advice of pesticides dealers having no knowledge about agriculture practices. The farmers were not used recommended POP of mustard crop and major gaps were observed between recommended technology and farmers practices (Singh et al 2019 and Kalita et al 2019). The highest gap (80%) was in use seed treatment followed by weed management, pest and disease management, seed treatment, application of Sulphur and use of variety (Table 2). Farmers are generally use hybrid seed (private company) or local variety instead of the recommended high yielding variety. They were not using seed treatment with fungicide or bio-fertilizers due to lack of knowledge and unavailability of material. Recommended fertilizers were not used due to lack of information. No weed management and control of diseases and pests were adopted due to lack of awareness. On the basis of observed gap, under the demonstration improved variety seed of CS-58, 60, PM-32, RH-725 and RH-761, fungicide and bio-fertilizer for seed treatment, herbicide for weed management and insecticide for plant protection measure were provided to the partner farmers by the Krishi Vigyan Kendra Karnal and other component viz. balanced application of fertilizer and

Table 1. Details of technology intervention and farmer's practices under FLDs on mustard in Karnal district of Haryana

Technology	Recommended practice	Farmer practice	Gap (%)
Variety	CS-58, CS-60, Pusa Mustard-32, RH-725 and RH-761	Local seed and seed of private company	22
Seed rate (kg/ha)	3.69	5	38
Spacing	Row to row 30 cm and plant to plant 10 cm.	No proper spacing	40
Seed treatment	Carbendazim @ 2.5gm/kg seed	No seed treatment	80
Fertilizers	Nitrogen-80 kg/ha., Phosphorus 30 kg/ ha, and Sulphur 12.5 kg /ha. (90%)	Non-judicious use of fertilizers, No use of Sulphur	38
Weed management	Pendimethalin @ 2.5 lit. /ha. was used 1-2 D.A.S as a pre-emergence and hand weeding at 15-20 DAS	No practice of hand weeding	70
Insect management	Spraying of Thiamethoxam 25% WG) 100 gm per hectare	No application	40
Diseases management	Two spray of Metalaxyl 8% WP + Mancozeb 64% @ 3gm/ litre of water at 15 days interval	One spray of Carbendazim 50% WP @ 1gm per litre of water	40

micronutrients and all other crop management practices were timely performed by the partner farmer itself under the supervision of KVK scientist.

Mustard yield: CFLD of mustard showed that the average seed yield of mustard through demonstrated improved technology ranged from 16.0 to 21.50 q/ha as compared to 12.30 to 16.00 q/ha under farmers practice (Local check). Average yield was 18.24 q/ha from demonstrated improved technology whereas, from farmer's practices was 14.15 q/ha. There was on an average 29.09 per cent increase in demonstration yield over local check. The variety CS-58 during 2018-19 and 2017-18 gave highest yield 21.50 and 21.05 quintal per hectare followed. The higher yield of mustard under demonstration against farmer practice was due to the use of latest variety, seed treatment with fungicide and bio-fertilizers and use of Sulphur nutrient and recommended package of practices suitable for agro-climatic zone of Karnal district. Fluctuations in productivity were mainly due to of variation in soil condition, its fertility levels, rainfall pattern, sowing time and crop management practices. The detailed analyses of rainfall pattern were given in Figure 1 during the five consecutive years. During 2019-20 and 2021-22, there were occurrences of heavy rainfall 303.1 mm and 191.2 mm respectively at the growth and maturity stage of the mustard crop due to that overall yield potential of mustard crop was reduced as compared to the other season. These observations confirm the findings of Kumar and Yadav (2007), Kumar (2014b) and Kumar (2013).

Technology gap: The technology gap which cover research issues to achieve potential yields ranged from 5 to 20.56 q/ha during different years of demonstration. Technology gap was maximum (20.56 q/ha) with demonstration variety RH-725 during 2021-22 and minimum (5 q/ha) with Pusa vijay during 2017-18. Mean technology gap during five years of demonstrations were 11.21q/ha for mustard cultivation in Karnal district. The perceived technical gap may be due to differences in crop management practices, soil fertility and agro-climatic situation of Karnal district. It showed the limitation in demonstrating of technology and weakness in our demonstrated technology. This also indicates the poor extension methodology, which resulted in low adoption of package of practice by farmer. Hence, extension methodology and a crop wise specific technological recommendation appear to be necessary to reduce the technology gap.

Extension gap: The extension gap ranging between 2.42-6.05 q/ha was observed between demonstrated technology and farmer's practices during five year of demonstration (Table 3). The extension gap was highest 6.05 q/ha and lowest 2.42 q/ha during the year 2017-18 and 2019-20, respectively. On an average extension gap during period of demonstration were 4.09 q/ha for mustard cultivation in Karnal district. So as to increase the farmer's income, there is demand to lesser the wider extension gap, therefore, it is necessity to provide the knowledge to the farmers through various means for more adoption of recommended high yielding latest varieties and implementation of latest crop production methodology (Reager et al 2020, Meena et al 2020).

Technology index: A perusal of data (Table 3) further indicates that values for technology index ranged from 20 to 57.11 percent. During five years of frontline demonstrations the highest technology index 57.11 per cent and lowest 20 per cent was recorded in variety RH-725 and Pusa Vijay

Table 2. Yield performance and yield analysis of demonstrated Mustard variety in Karnal district of Haryana

Year	No. of demo	Area (ha.)	Variety	IT average yield (q/ha)	FP average yield (q/ha)	% increase in yield over FP	IT yield (q/ha) over FP
2017-18	8	3.23	CS-58	21.05	15.00	43.33	6.05
	5	2	Pusa Vijay	20.00	15.00	33.33	5.00
	11	4.45	RH-749	20.25	15.00	35	5.25
2018-19	15	38	CS-56	19.21	16.00	20.06	3.21
	15	38	CS-58	21.50	16.00	34.37	5.5
2019-20	25	10	CS-58	16.00	13.58	17.82	2.42
	25	10	CS-60	16.55	13.58	21.87	2.97
2020-21	125	50	CS-58	18.00	14.68	22.61	3.32
2021-22	125	50	PM-32	17.14	12.30	39.34	4.84
			RH-725	15.44	12.30	25.52	3.14
			RH-761	15.59	12.30	26.74	3.29
Total/Mean	354	205.68	-	18.24	14.15	29.09	4.09

during year of 2017-18, respectively. Variation in technology index during five seasons might be attributed to dissimilarity in the weather parameters. Further, on an average technology index 36.85 per cent was observed during five experimental years of mustard in Karnal district, which shows the efficacy of better performance of technical interventions. This will increase the adoption of demonstrated technical intervention to increase the yield performance of mustard at farmer's field.

Economics: Economic assessment for recommended technology under FLD were calculated (Table 4) on the basis of prevailing market rates and recorded higher gross return (Rs. 90,300 /ha) and net return (Rs. 66,170 /ha) with improved technology demonstration compared to farmer's practice in the year 2018-19 in CS-58 variety. The present findings were concluded that higher net return ranged from Rs 36,055 to 66,170/ha over five years and its mean value was Rs 53,709/ha. However, in farmer's practices the net return ranged from Rs.28148 to Rs. 44,355 /ha over five years and its mean value was Rs.37,527 /ha. The benefit cost ratio was maximum (3.74) in improved technology in year 2018-19 in CS-58 variety and minimum (2.45) was in year 2019-20 in CS-60 variety. However, under farmer practice maximum B:C ratio was recorded (2.94) in 2018-19 and minimum (2.20) in 2019-20. Higher B:C ratio and additional returns clearly shows that demonstrated techniques were found cost effective & feasible for yield enhancement of mustard on farmer fields. Farmers were also found greatly

Table 3. Gap analysis in mustard under front line demonstration and farmer practice

Season and year	Variety	Technology yield gap (q/ha)	Extension yields gap (q/ha)	Technology index (%)
2017-18	CS-58	6.95	6.05	24.82
	Pusa Vijay	5	5.00	20.00
	RH-749	13.75	5.25	40.44
2018-19	CS-56	6.79	3.21	26.11
	CS-58	6.50	5.5	23.21
2019-20	CS-58	12	2.42	42.85
	CS-60	12.45	2.97	42.93
2020-21	CS-58	10	3.32	35.71
2021-22	PM-32	9.96	4.84	36.75
	RH-725	20.56	3.14	57.11
	RH-761	19.41	3.29	55.45
Mean		11.21	4.09	36.85

Table 4. Economic analysis of FLDs on mustard in Karnal district of Haryana

Season and year	Variety Demonstrated	Average cost of cultivation (₹/ha)		Additional cost in IT (₹/ha.)	Sale price (₹q^{-1})	Average gross return (₹/ha)		Additional return in IT (₹/ha)	Average net return (₹/ha)		Effective gain (₹/ha)	Benefit-Cost Ratio	
		IT	FP			IT	FP		IT	FP		IT	FP
Rabi 2017-18	CS-58	23640	22120	1520	4000	84200	60000	24200	60560	37880	22680	3.56	2.71
	Pusa Vijay	23640	22120	1520	4000	80000	60000	20000	56360	37880	18480	3.38	2.71
	RH-749	23640	22120	1520	4000	81000	60000	21000	57360	37880	19480	3.42	2.71
Rabi 2018-19	CS-56	24130	22845	1285	4200	80682	67200	13482	56552	44355	12197	3.34	2.94
	CS-58	24130	22845	1285	4200	90300	67200	23100	66170	44355	21815	3.74	2.94
Rabi 2019-20	CS-58	24745	23456	1289	3800	60800	51604	9196	36055	28148	7907	2.45	2.20
	CS-60	24745	23456	1289	3800	62890	51604	11286	38145	28148	9997	2.54	2.20
Rabi 2020-21	CS-58	27345	25350	1995	4650	83700	68262	19890	56355	42912	13443	3.06	2.69
Rabi 2021-22	PM-32	27475	25650	1825	5100	87414	62730	24684	59939	37080	22859	3.18	2.44
	RH-725	27475	25650	1825	5100	78744	62730	16014	51269	37080	14189	2.86	2.44
	RH-761	27475	25650	1825	5100	79509	62730	16779	52034	37080	14954	2.89	2.44
Mean	-	25313	23751	1562	4359	79022	61278	18148	53709	37527	16182	3.13	2.58

convinced with the mustard varieties CS-58 & Pusa Mustard-32 and other latest technological interventions due to higher economic returns with least additional investment and management practices. The variation in cost benefit ratio during different years might be due to variation in yield performance and input output cost in that particular year with domestic price support programme. Earlier researchers were also observed similar trend (Meena and Singh 2019, Kumar et al 2020, Shivran et al 2020, Singh et al 2020, Puniya et al 2021.

CONCLUSION

The results revealed that both extension and technology gap reduction is essential to further increase the production at farmers field level. It can be achieved by demonstrating/educating recent technologies and methodologies in agriculture to the farming community at micro-level. Demonstration of improved mustard production technology satisfied fellow farmer to adopt the crop diversification technique with improved technology for better income in Karnal district of Haryana.

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Prevalence of Chickpea Wilt in Jammu Sub-Tropics

Seethiya Mahajan, Santosh Kumar Singh[1] and Deepak Mahajan[2]

Division of Plant Pathology, Faculty of Agriculture
Khalsa College of Agriculture, Amritsar-143 001, India
[1]Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha-180 009, India
[2]Khalsa college of Veterinary, Amritsar- 143 001, India
E-mail: Seethiyamahajan@gmail.com

***Abstract*:** Fortnightly surveys of different chickpea growing areas of Jammu sub-tropics revealed that overall disease incidence of 15.64 and 16.86 per cent, during *Rabi* seasons of 2016-17 and 2017-18, respectively. *Fusarium oxysporum* f. sp. *ciceri* was isolated from wilt infected chickpea plants and soil samples collected from chickpea fields of Jammu sub-tropics. Pathogenicity test of different isolates of Foc exhibited disease incidence (6.26-66.65%) in susceptible cultivar (C-235). Wilt symptoms in adult plants were quite common at flowering and pod stages. The affected plants showed characteristic wilting *viz.,* drooping of the petioles, rachis and leaflets.

Keywords: Prevalence, Chickpea, *Fusarium oxysporum* f. sp. *ciceri,* Pathogenicity

Pulses, being legume crops play a vital role in improving soil fertility and conserve natural resources which are essential for sustainable agriculture. Chickpea (*Cicer arietinum* L.) a self-pollinating diploid (2n=2x=16) crop is the world third most important legume. India is a main chickpea producing country followed by Pakistan and Turkey (FAOSTAT 2007). The chick pea production in India has gone up from 38.55 to 112.29 lakh tonnes during 2000-01 to 2017-18, while the area has also gone up from 51.85 to 105.61 lakh ha, whereas, the yield has steadily increased from 744 kg/ha to 1063kg/ha during the same period (Samriti et al 2020). The pathogen of chickpea wilt disease is seed- borne (Pande et al 2007) as well as soil borne nature (Jimenez- Fernandez et al 2011). It can survive in soil for more than 6 months in the absence of its host and can cause severe damage to crop yield and disease can appear at any stage of the plant growth. Early wilting is reported to cause more loss than late wilting, but seeds from late wilted plants are lighter, rougher, and duller than those from healthy plants.

Hence, it is most important to carry out screening of chickpea genotypes under artificial inoculated conditions to identify sources of resistance. In order to develop the disease resistant and high yielding cultivars, it is essential to study and understand the variability in the pathogen. Therefore, integrated management strategies are the possible solutions to maintain plant health mainly for soil borne plant pathogens. These strategies include modification of cultural practices, growing of resistant varieties with minimum application of chemicals (Bendre and Barhate, 1998), and encouragement of beneficial microbial population to reduce pathogen inoculation. Keeping in view the importance of the crop, losses caused to it and lack of information regarding the status of the disease in Jammu subtropics.

MATERIAL AND METHODS

The field experiments of the present investigation on wilt of chickpea were conducted at Research Farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha situated at 32.43° N latitude, 74.54° E longitude and 327 meters above sea level during *Rabi* 2016-17 and 2017-18 cropping seasons. The laboratory experiments were conducted in the Division of Plant Pathology, SKUAST- Jammu. Materials used and methodology adopted for field as well as laboratory experimentation are described as below:

Field survey of chickpea wilt: Fortnightly field surveys for recording disease incidence were during *Rabi* 2016-17 and 2017-18 crop seasons conducted in chickpea growing areas of Jammu subtropics *viz*., Jammu, Samba and Kathua districts. In each district, the major chickpea growing blocks were identified, three villages per block and five fields per village were further selected for recording disease incidence on chickpea plants. For recording the observations from each measuring 5m^2 area were randomly selected and ten plants were tagged for recording disease incidence and average disease incidence in the village was recorded. The per cent disease incidence on infected plants due to chickpea wilt was calculated

Isolation and identification of pathogen associated with chickpea wilt: During the field surveys, diseased chickpea plants with wilt symptom were collected from different districts were carefully uprooted and bagged separately in perforated polythene bags and brought to the laboratory. Roots of infected chickpea plants were longitudinally cut with a sharp and sterilized blade into two halves from the centre. The infected roots were cut into small bits of 2-3 mm size surface sterilized with sodium hypochlorite (4%) solution for 30 seconds, rinsed thrice with sterile distilled water, blotted dry, transferred to sterilized PDA plates, incubated in BOD incubator at 28±1°C for 7-10 days and allowed the fungal pathogen to grow. Colony characteristics were studied and measurements recorded daily until the growth was static. Pure fungal colonies which developed from the diseased bits were transferred to PDA slants and incubated at room temperature for 15 days. Pure culture of the fungus was maintained at 4°C for further studies.

Symptomatology of fusarium wilt in chickpea: The symptoms of wilt were observed at two different stages. At seedling stage, diseases were observed three weeks after sowing of chickpea plants. Symptoms were expressed as wilting of leaves followed by drooping of leaves and branches, uneven shrinking of the stem above the collar region, which ultimately lead to collapse of chickpea seedlings, without discoloration in 20-30 days after sowing. When wilt affected seedlings were uprooted, the roots of the affected plant apparently appeared healthy. At adult stage, wilt symptoms in adult plants were quite common at flowering and pod stages. The affected plants showed characteristic wilting viz*.,* drooping of petioles, rachis, and leaflets. The lower leaves were chlorotic, most of the leaves drooped while still green. Gradually, all the leaves become yellow and then light brown or straw coloured. Two types of wilt symptoms were observed viz*.,* partial wilt and complete wilt. In case of complete wilt, all branches were affected on both side of plant. Drooped leaves later dried, but remained attached to the plant for long time. When stem of the wilted chickpea plant was split open longitudinally with a sharp- edged blade, internal was clearly distinctive which is quite characteristic of fusarium wilt. The xylem in the centre inner portion was discoloured as yellow to dark brown, pink to black.

Pathogenicity and virulence of *Fusarium oxysporum* f. sp. ciceri: *Fusarium oxysporum* f. sp. ciceri was tested for proving the pathogenicity of chickpea wilt. Pre-sterilized soil was inoculated with pure culture of *F. oxysporum* f. sp. *ciceri* isolates and seeds of susceptible chickpea variety C-235 were planted, regularly watered, and constantly observed from seedling emergence to development of wilt symptoms. The fungus produced initial symptoms on chickpea seedling after 15 days of inoculation under controlled conditions having characteristics drooping of petioles, rachis, and leaflets. The pathogen were re-isolated from collar and affected root region of plant was made and pathogenic cultures obtained were compared with original culture of Foc. Prepared mass multiplied (*Fusarium oxysporum* f. sp. ciceri) on sterilized sorghum or wheat grains. The grains were softened by boiling in water for 20 minutes. Excess water was removed by draining also the grains were spread to cool down and decrease the moisture content. Calcium carbonate (2g) was added in 100g of pre-boiled semi-dried sorghum grains to remove excess moisture. The content was transferred to conical flasks and autoclaved at 15 lb/inch^2 pressure for 15 minutes. After cooling these flasks were inoculated with 4 discs of 5.0 mm diameter mycelial growth of three-day old culture of *F. oxysporum* f. sp. *ciceri* grown on PDA plate. The flasks were incubated at 28±1°C for seven days for colonization of sorghum grains. After proper colonization in the flasks, inoculum was mixed with sterilized soil @ 100g/kg soil and filled in the earthen pots (22.5cm diameter). The seeds of chickpea were moistened in sterilized water and simultaneously inoculated with powdered inoculum @ 5g/kg seed. These seeds were dried in shade and 10 seeds per pot were sown. Three replications per treatment were laid and an uninoculated control was also maintained. The plants were regularly watered and proper care was taken for maintenance of plants. Chickpea plants were regularly observed for the development of wilt symptoms properly recorded was maintained on daily basis and were recorded *viz* numerical rating of 0, 1, 2, 3, 4 and 5 on the basis of initial plant count and total number of wilted plants in each genotype (Nene *et. al.*1981). The highly resistant plant having score of 0, while those with highest infection i.e. highly susceptible having score of 5.

RESULTS AND DISCUSSION

Status of wilt of chickpea in Jammu Division: Extensive fortnight surveys were undertaken during *Rabi* seasons 2016-17 and 2017-18, in major chickpea growing districts of Jammu division viz*.,* Jammu, Samba and Kathua districts. During surveillance, certain location chickpea wilt having were overall range of 8.11-21.67 and 10.98-23.99 per cent respectively with an overall mean incidence of 15.64 and 16.86 per cent, respectively (Table 1). However, maximum disease incidence (21.67% and 23.99% respectively) was recorded in Chatha of Satwari block followed by Lehar of Akhnoor block, whereas, the lowest disease incidence was in Panotra Chak of Satwari block followed by Palori of Akhnoor. In Samba district, the highest disease incidence (20.76% and 21.98% respectively) was recorded in Dhiansar of Vijaypur block followed and Sumb of Samba block whereas lowest disease incidence was in Sanoora of Ghagwal block. In Kathua district, the average disease incidence ranged from 8.11 to 15.44 and 10.98-16.34 per cent respectively. The

Table 1. Area and source of isolation of *Fusarium oxysporum* f. sp. *ciceri*

Location	Isolate of *F. oxysporum* f. sp. *ciceri* (FOC)	Host variety	Growth habit
Jammu district			
Bishnah	FOC-1	C-235	Fast
	FOC-2	C-235	Slow
	FOC-3	C-235	Moderate
	FOC-4	C-235	Poor
	FOC-5	C-235	Poor
	FOC-6	C-235	Slow
	FOC-7	C-235	Poor
Jammu	FOC-8	Local cultivar	Moderate
	FOC-9	Local cultivar	Slow
	FOC-10	Local cultivar	Poor
	FOC-11	Local cultivar	Slow
	FOC-12	Local cultivar	Poor
	FOC-13	Local cultivar	Slow
Sungal	FOC-14	VBN-6	Moderate
	FOC-15	VBN-6	Poor
	FOC-16	VBN-8	Slow
	FOC-17	VBN-8	Moderate
	FOC-18	VBN-8	Fast
	FOC-19	Local cultivar	Moderate
	FOC-20	Local cultivar	Moderate
Samba district			
Vijaypur	FOC-21	PBG-1	Poor
	FOC-22	PBG-1	Slow
	FOC-23	PBG-1	Slow
	FOC-24	PBG-1	Slow
	FOC-25	PBG-1	Moderate
Samba	FOC-26	SCS-3	Poor
	FOC-27	SCS-3	Poor
	FOC-28	SCS-3	Fast
	FOC-29	SCS-3	Poor
	FOC-30	SCS-3	Slow
	FOC-31	SCS-3	Poor
Ghagwal	FOC-32	GNG 496	Slow
	FOC-33	GNG 496	Slow
	FOC-34	GNG 496	Fast
	FOC-35	GNG 496	Slow
	FOC-36	GNG 496	Slow
Kathua district			
Hiranagar	FOC-37	GNG 496	Fast
	FOC-38	GNG 496	Fast
	FOC-39	GNG 496	Moderate
	FOC-40	GNG 496	Moderate
	FOC-41	GNG 496	Fast
Barnoti	FOC-42	Local Variety	Slow
	FOC-43	Local Variety	Fast
	FOC-44	Local Variety	Slow
	FOC-45	Local Variety	Poor
	FOC-46	Local Variety	Poor
Kathua	FOC-47	Gaurav	Slow
	FOC-48	Gaurav	Moderate
	FOC-49	Gaurav	Slow
	FOC-50	Gaurav	Slow

Table 2. Status of chickpea wilt in Jammu sub-tropics during *Rabi* 2016-17 and 2017-18

Block	Location	Disease incidence (%)		
		2016-17	2017-18	Pooled
Jammu district				
Bishnah	Deoli	15.32	16.78	16.04
	Dhabad	20.18	20.97	20.57
	Pataidi	17.98	18.87	18.42
	Mean ± S.E.	17.82± 1.93	18.87 ± 1.72	18.34± 0.05
Satwari	Panotra Chak	12.98	14.87	13.92
	Sohanjna	18.89	19.98	19.43
	Chatha	21.67	23.99	22.83
	Mean ± S.E.	17.84 ± 2.56	19.61 ± 2.63	18.72± 0.18
Akhnoor	Lehar	20.76	21.54	21.15
	Palori	14.87	15.98	15.42
	Pangiari	17.11	18.99	18.04
	Mean ± S.E.	17.58 ± 1.72	18.83 ± 1.60	18.20± 0.05
Samba district				
Vijaypur	Chhanni	17.90	18.94	18.41
	Dhiansar	20.76	21.98	21.36
	Salmeri	15.87	16.10	15.98
	Mean ± S.E.	18.17 ± 1.42	19.00 ± 1.70	18.58± 0.41
Samba	Nanke	16.98	17.98	17.47
	Sumb	18.77	19.47	19.11
	Rakh	15.54	16.09	15.81
	Mean ± S.E.	17.09 ± 0.93	17.84 ± 0.97	17.46± 0.02
Ghagwal	Ragu Chak	19.98	20.98	20.35
	Sanoora	11.46	12.89	12.17
	Harsat	15.99	16.67	16.33
	Mean ± S.E.	15.81 ± 2.46	16.84 ± 2.33	16.28± 0.00
Kathua district				
Hiranagar	Kootah	8.11	10.98	9.54
	Jatwal	10.67	12.87	11.76
	Tokal	11.32	12.76	12.03
	Mean ± S.E.	10.03 ± 0.98	12.20 ± 0.61	11.11± 0.04
Barnoti	Budhi	11.87	12.65	12.25
	Sonthal	13.45	14.98	14.21
	ChhannRorian	15.44	16.34	15.88
	Mean ± S.E.	13.58 ± 1.03	14.65 ± 1.07	14.11± 0.03
Kathua	Rajbagh	14.78	15.54	15.15
	Lagate	12.45	13.67	13.05
	Hatli	11.45	12.67	12.05
	Mean ± S.E.	12.89 ± 0.98	13.96 ± 0.84	13.41± 0.00
	Overall mean	15.64	16.86	16.25
	Overall range	8.11 – 21.67	10.98 – 23.99	9.54-22.83

highest disease incidence was recorded in Chhann Rorian of Barnoti block followed by Rajbagh of Kathua block. Many workers have reported chickpea wilt throughout the crop season with maximum incidence and damage in the chickpea crop at seedling stage than at maturity. Disease was prevalent in all the chickpea growing areas surveyed. The wilt symptoms at seedling stage were observed about 2-3 weeks after sowing in the first fortnight of November. The affected seedlings retained almost green colour. The whole lot of chickpea seedling collapsed and laid flat on the ground. Such collapsed seedlings, when uprooted usually showed uneven shrinking of the stem above and below the collar region. Upon dissection, collar region showed black discoloration of internal tissues. The wilt affected mature plants showed typical wilting accompanied by drooping of petioles and rachis along with leaflets.

Pathogenicity of *Fusarium oxysporum* f. sp. *ciceri* isolates on susceptible chickpea cultivar (C-235): The pathogenicity test of *F. oxysporum* f. sp. *ciceri* (Foc) isolate causing chickpea wilt was determined on susceptible chickpea cultivar (C-235) grown in sterilized pot soil at seedling stage. Data (Table 2) revealed that chickpea wilt incidence ranged between 6.26-66.65 per cent. However, eight isolates of the wilt pathogen *viz.*, FOC-1, FOC-18, FOC-28, FOC-34, FOC-37, FOC-38, FOC-41 and FOC-43 exhibited excellent virulence pattern and showed symptoms 15 days after sowing; 10 isolates exhibited good virulence pattern and wilt symptoms expressed in 21 days after sowing; 19 isolates recorded fair virulence pattern and 13 isolates exhibited poor virulence pattern and the disease symptoms were visible 32 days after sowing. None of the Foc isolate was avirulent. Each inoculated isolate of Foc was re-isolated from the infected chickpea plants and compared with the original culture. Morphological characters of the isolated pathogen were found to be similar to those of the original culture. Hence, it was confirmed that the fungus *F. oxysporum* f. sp. *ciceri* was pathogenic and responsible for causing wilt of chickpea, thereby confirming the Koch's postulates. However, no symptoms developed on uninoculated chickpea plants throughout the crop season. The findings are also in consonance with the studies of Patra and Biswas (2016) on cultural, morphological and pathogenic variability among the 11 isolates of *F. oxysporum* f. sp. *ciceri* causing wilt of chickpea who observed that most of the isolates were highly pathogenic. Patil et al (2017) proved the pathogenicity of *F. oxysporum* f. sp. *ciceri* isolates by using highly susceptible chickpea variety JG-62 and resistant variety JG-315 and reported that initiation of disease due to different isolates ranged from 5-10 days depending upon susceptibility of the host.

Table 3. Pathogenicity of *Fusarium oxysporum* f. sp. *ciceri* isolates on susceptible chickpea cultivar (C-235)

Isolate	Location	Disease incidence (%)	*Virulence pattern
Jammu district			
FOC-1	Bishnah	66.65	++++
FOC-2		26.26	++
FOC-3		33.13	+++
FOC-4		13.39	+
FOC-5		6.86	+
FOC-6		20.00	++
FOC-7		6.56	+
FOC-8	Satwari	33.73	+++
FOC-9		20.60	++
FOC-10		13.43	+
FOC-11		26.96	++
FOC-12		13.73	+
FOC-13		26.66	++
FOC-14	Sungal	33.83	+++
FOC-15		13.23	+
FOC-16		20.50	++
FOC-17		33.73	+++
FOC-18		46.76	++++
FOC-19		33.83	+++
FOC-20		33.93	+++
Samba district			
FOC-21	Vijaypur	6.26	+
FOC-22		26.06	++
FOC-23		20.50	++
FOC-24		20.09	++
FOC-25		33.37	+++
FOC-26	Samba	13.34	+
FOC-27		13.63	+
FOC-28		46.86	++++
FOC-29		13.73	+
FOC-30		20.70	++
FOC-31		13.93	+
FOC-32	Ghagwal	26.36	++
FOC-33		26.96	++
FOC-34		40.40	++++
FOC-35		26.76	++
FOC-36		26.86	++
Kathua district			
FOC-37	Hiranagar	40.60	++++
FOC-38		46.46	++++
FOC-39		33.93	+++
FOC-40		33.93	+++
FOC-41		40.50	++++
FOC-42	Barnoti	26.86	++
FOC-43		40.90	++++
FOC-44		26.86	++
FOC-45		6.76	+
FOC-46		13.53	+
FOC-47	Kathua	26.96	++
FOC-48		33.53	+++
FOC-49		20.80	++
FOC-50		26.56	++

*Absent Avirulent
+ Poor (Symptoms appeared 32 DAS)
++ Fair (Symptoms appeared 28 DAS)
+++ Good (Symptoms appeared 21 DAS)
++++ Excellent (Symptoms appeared 15 DAS)

Table 4. Sporulation of *Fusarium oxysporum* f. sp. *ciceri* isolates on PDA

Isolate	Spore density [No. of spores/ microscopic field (10x)]			Total no. of spores	Grade
	Microconidia	Macroconidia	Chlamydospore		
FOC-1	34	23	11	68	++++
FOC-2	20	11	4	35	++
FOC-3	29	18	7	54	+++
FOC-4	12	7	3	22	+
FOC-5	9	5	1	15	+
FOC-6	20	13	4	37	++
FOC-7	11	5	1	17	+
FOC-8	29	19	2	51	+++
FOC-9	18	12	2	32	++
FOC-10	13	6	4	23	+
FOC-11	25	14	3	42	++
FOC-12	25	11	2	38	++
FOC-13	24	14	2	40	++
FOC-14	20	11	4	35	++
FOC-15	17	12	3	32	++
FOC-16	23	12	3	38	++
FOC-17	20	13	1	34	++
FOC-18	31	24	7	62	++++
FOC-19	26	19	7	52	+++
FOC-20	24	17	6	47	+++
FOC-21	13	9	1	25	+
FOC-22	17	11	4	32	++
FOC-23	22	10	5	37	++
FOC-24	25	14	3	42	++
FOC-25	27	17	2	46	+++
FOC-26	15	7	3	25	+
FOC-27	12	6	4	22	+
FOC-28	31	25	6	62	++++
FOC-29	15	9	4	28	+
FOC-30	22	11	2	35	++
FOC-31	13	8	3	24	+
FOC-32	24	12	1	37	++
FOC-33	22	14	3	39	++
FOC-34	29	19	2	50	+++
FOC-35	20	11	3	34	++
FOC-36	22	9	3	34	++
FOC-37	19	11	2	32	++
FOC-38	31	21	6	58	+++
FOC-39	29	22	4	55	+++
FOC-40	28	19	5	52	+++
FOC-41	21	14	2	37	++
FOC-42	24	16	1	41	++
FOC-43	29	20	2	51	+++
FOC-44	25	16	3	44	++
FOC-45	14	6	0	20	+
FOC-46	11	7	4	22	+
FOC-47	24	11	3	38	++
FOC-48	28	17	3	48	+++
FOC-49	21	14	4	39	++
FOC-50	21	14	3	38	++
CD (p=0.05)				2.98	

Grade	Sporulation	Spores/ microscopic field
++++	Very good	>60
+++	Good	45.1-60
++	Moderate	30.1-45
+	Poor	<30

Sporulation of *Fusarium oxysporum* f. sp. *ciceri* isolate on PDA: The growth of *F. oxysporum* f. sp. *ciceri* (Foc) was drastically reduced below 15°C and started declining above 35°C as higher temperatures did not favour growth of the fungus. Best growth of the pathogenic fungus was recorded between 25-30°C. The results (Table 3) revealed that all the fifty isolates of Foc tested during the present studies exhibited good fungal growth and sporulation on PDA culture medium The spore density of microconidia, macroconidia and chlamydospores, however, varied from in different isolate of the fungus.

With respect to microconidia, maximum spore density of 34 was observed in FOC-1 followed by 31 in FOC-18, FOC-28 and FOC-38, whereas minimum spore density of 9 was in FOC-5. With respect to macroconidia, maximum spore density of 25 was in FOC-28 followed by 24 in FOC-18; 23 in FOC-1 and 22 in FOC-39, whereas minimum spore density of 5 was in FOC-5 and FOC-7. With respect to chlamydospore, maximum spore density of 11 was observed in FOC-1 followed by FOC-3, FOC-18 and FOC-19; whereas minimum spore density of 1 in FOC-5, FOC-7, FOC-17, FOC-21, FOC-32 and FOC-42. Three isolates *viz.,* FOC-1, FOC-18 and FOC-28 were having very good sporulation with >60 spores/microscopic field; 11 isolate *viz.,* FOC-3, FOC-8, FOC-19, FOC-20, FOC-25, FOC-34, FOC-38, FOC-39, FOC-40, FOC-43 and FOC-48 had good sporulation with 45.1-60 spores/microscopic field; 25 isolate were having moderate sporulation with 30.1-45 spores/microscopic field and 11 isolates recorded poor sporulation with <30 spores/microscopic field. Nath et al (2017) also observed that different isolates of *F. oxysporum* f. sp. *ciceri* infecting chickpea were collected from major chickpea growing areas of Bangladesh and varied significantly in cultural, morphological and physiological traits, i.e. colony color, shape, margin and texture; mycelial radial growth and spore production. The mycelial radial growth and sporulation of *F. oxysporum* was maximum for all the isolates at 25°C after seven days of inoculation, which was reduced drastically below 15°C and above 35°C. The highest number of macro spores ($3.27x10^5$ ml^{-1}) and micro spores ($4.06 x10^5$ ml^{-1}) were produced on PDA.

CONCLUSION

Wilt symptoms in adult plants were abundant at flowering and pod stages. Fortnightly surveys undertaken during *Rabi* seasons of 2016-17 and 2017-18 revealed that wilt disease appeared on chickpea crop at all the locations and overall range of disease incidence in 2016-17 and 2017-18. Based on pathogenicity, Foc isolates causing chickpea wilt was confirmed on the susceptible chickpea cultivar (C-235) grown in sterilized pot soil at seedling stage. All the fifty isolates of Foc exhibited good fungal growth and sporulation on PDA culture medium where Maximum number of spores 68 total was observed in FOC-1, while minimum number of spores 15 was observed in FOC-5.

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Influence of Organic Mulches on Soil Moisture Conservation in Maize (*Zea mays* L.) in Alfisols of Eastern Dry Zone of Karnataka

Shashikanth Murukannappa and Altaf Kuntoji[1]

Department of Soil and Water Engineering, [1]Department of Soil Science and Agricultural Chemistry
University of Agricultural Sciences, GKVK, Bengaluru-560 065, India
E-mail: shashishanu786@gmail.com

Abstract: A field experiment was conducted at Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bangalore during *kharif* 2019 to study the influence of different organic mulches on soil moisture conservation in *Alfisols* of eastern dry zone of Karnataka. The experiment consists of seven treatments *viz*, mulching with paddy straw, mulching with saw dust, mulching with grass, mulching with newspaper, mulching with dry leaves, dust mulching and no mulch (control) which were replicated thrice in randomized complete block design. Maize crop was sown as a test crop. The results of study revealed that mulching with dry leaves treatment recorded significantly higher soil moisture content 24.07, 18.90, 21.70 and 20.73 per cent at 30, 51, 72 and 93 DAS respectively compare to other treatments at 15 cm depth. The similar treatment recorded significantly higher soil moisture 24.83, 20.87, 22.90 and 21.80 per cent at 30, 51, 72 and 93 DAS respectively at 15-30 cm depth. Overall, the mulching with dry leaves treatment showed higher soil moisture content, higher infiltration rate and lower bulk density compare to other treatments.

Keywords: Organic mulches, Dust mulch, Soil moisture content, Dry leaves mulching, Paper mulch

The biggest challenge in present day agriculture is to produce more food grains per every drop of rain water to feed the global population utilizing very limited natural resources. Due to change in climatic condition coupled with uneven and erratic rainfall distribution leading more deterioration of land, water and environment which drastically reduce the production level. India is the seventh-largest country by area in the world (2.4 per cent of the world area and second-most populated 1.32 billion people constituting 17.74 per cent of the world population) is expected to produce 350 MT of food grain by the year 2050. Presently, India's total food grain production is 276.5 MT out of which 9 per cent (22.23 mt) is contributed by maize crop alone. In Karnataka, maize (*Zea Mays* L) is grown over an area of 1.18 million hectares with production of 3.27 million tonnes and average productivity of maize is 27.73 q ha^{-1} (Anonymous 2016). In our state presently most of the crops like cotton, groundnut, ragi, sorghum have been replaced by maize which is having multipurpose as feed, food and fodder. Soil moisture is one of the major factors limiting crop production under rainfed situation, suitable conservation measures lead to higher yields but the Maize is most exhaustive crop and depletes the soil moisture and nutrients resulting in reduction in productivity. Mulching is one of the effective soil moisture conserving practice, reducing evaporation and regulating the soil temperature (Ratan 2004 and Pervaiz et al 2009). The use of different organic mulching materials is the low cost technologies (Mupangwa et al 2013) which helps in improving soil conservation and soil fertility as well apart from several advantages such as regulating soil surface temperatures due to their higher surface ground cover, increasing soil organic matter content to the soil thus improving the soil physical properties, controlling soil erosion and conserving it more effectively with this an experiment was conducted at UAS,GKVK Bengaluru to know the effects of different organic mulches on soil moisture conservation in Maize (*Zea Mays* L.) in Alfisols of Eastern Dry Zone of Karnataka.

MATERIAL AND METHODS

A field experiment was conducted at Department of Soil and Water Engineering, College of Agricultural Engineering, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bangalore during *kharif* 2019 and experiment was conducted to study the influence of different organic mulches on soil moisture in maize (*Zea mays* L.) in Alfisols of eastern dry zone of Karnataka.. Composite soil sample from 0-30 cm depth was collected randomly from the experimental area before sowing of the crop and determine the initial soil moisture condition and also various soil physio-chemical properties (Table1). The soil was red sandy loam in texture and slightly acidic in reaction (pH 5.80) with electrical conductivity was 0.15 dsm^{-1}, medium in soil organic carbon (0.42 per cent), available phosphorus (17.60 kg ha^{-1}) and potash (109 kg ha^{-1}), low in available nitrogen (159 kg ha^{-1}). Initial soil moisture content at experimental plot was 16.80%. The measured infiltration rate and bulk density in the experimental plot were 4.55 cm hr^{-1} and 1.53 g cc^{-1} before starting of the experiment.

The experiment consists of seven treatments in randomized complete block design and replicated thrice (Table 2). The mulching practices were carried out at 30 days after sowing. The soil samples were collected with the help of screw auger from 0 to 15 cm and 15 to 30 cm depths from each plot at 30, 72 and 93 days after sowing. The moisture content was determined by gravimetric method (Piper 1966).

RESULTS AND DISCUSSION

Effect on soil moisture condition before sowing: The soil moisture content in the experimental plot was 16.80 per cent (Table 1). The probable reason for this soil moisture content in the experimental field could be due to even distribution of rain fall over a period and there is no significant difference in the field elevation too.

Table 1. Soil physic-chemical properties of experimental site before sowing of crop

Initial soil properties	Values
Soil texture	Sandy loam
Soil pH	5.80
EC (dsm^{-1})	0.15
OC (%)	0.42
Available Nitrogen (kg ha^{-1})	159
Available phosphorus (kg ha^{-1})	17.60
Available potassium (kg ha^{-1})	109
Soil moisture content (%)	16.80
Infiltration rate (cm h^{-1})	4.55
Bulk density (g cc^{-1})	1.53

Effect of different organic mulches on soil moisture content at different depths: soil moisture content at 0-15 cm depth differs significantly at all stages of crop growth throughout the experiment (Table 2). However, mulching with dry leaves in maize plot (T_5) recorded significantly higher soil moisture content of 24.07 per cent after three weeks of treatment and closely followed by mulching with paddy straw and mulching with grass, mulching with newspaper. The same treatment recorded significantly higher soil moisture content at six weeks (21.70%) and nine weeks (20.73%) of treatment imposed. The control treatment was recorded significantly lower soil moisture content of 14.67 to 16.10 per cent respectively at all growth stages of the experiment period. The soil moisture content measured at 15-30 cm depth at different crop growth stages differed significantly at all stages of the crop growth throughout the experimental period. Mulching with dry leaves recorded significantly higher moisture content of 20.87per cent after three weeks of treatment imposed which was significantly superior over control treatment. The same treatment recorded significantly higher soil moisture content at six weeks (22.90%) and nine weeks (21.80 %) of treatment imposed. In general, all the stages of the crop growth mulching with paddy straw and mulching with grass are in the next order of merit and are on par with mulching with dry leaves.

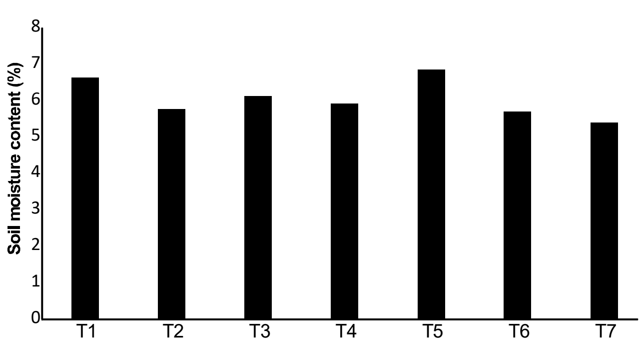
Effect of rainfall characteristics on per cent soil moisture condition after crop harvest: The data pertaining to soil moisture level after crop harvest is presented in Figure 1 and soil moisture content differs significantly after crop harvest

Table 2. Soil moisture content (%) as influenced by different organic mulches in maize at different depths (0 -15 cm and 15-30 cm)

Treatments	Soil moisture content (%)							
	0 - 15 cm depth				15-30 cm depth			
	30 DAS	51 DAS	72 DAS	93 DAS	30 DAS	51 DAS	72 DAS	93 DAS
T_1: Mulching with paddy straw	20.70	17.97	20.80	19.70	23.44	20.30	22.30	21.40
T_2: Mulching with saw dust	16.45	15.70	17.70	16.60	19.47	19.47	18.87	18.00
T_3: Mulching with grass	19.99	16.70	19.20	18.77	21.30	19.80	20.80	19.53
T_4: Mulching with newspaper	16.92	16.27	18.13	17.30	20.36	19.53	19.50	18.50
T_5: Mulching with dry leaves	24.07	18.90	21.70	20.73	24.83	20.87	22.90	21.80
T_6: Dust mulching	16.09	15.37	17.10	16.23	18.30	18.47	18.50	17.30
T_7:Control	14.67	15.00	16.10	15.57	17.53	17.17	17.17	16.37
CD (P =0.05)	0.60	0.43	0.18	0.45	0.55	0.44	0.20	0.39

even under longer dry spell the study indicated that the mulching treatment with dry leaves recorded the higher soil moisture content of 6.86 per cent closely followed by mulching with paddy straw (6.64%), mulching with grass (6.12%), mulching with newspaper (5.92%). The control plot recorded the lowest soil moisture content (5.40%) after harvest of maize crop. The probable reason for significant variation in soil moisture content among different mulching treatment could be due to organic mulches covered the soil between the crop rows helps in more infiltration of rainwater, reducing runoff and soil loss. In addition, mulching materials helps to prevent evaporation of soil moisture, improves soil structure and water holding capacity of the soil too. The supporting reason may also could be reduction in growth of weeds due to different organic mulches might facilitated better moisture conservation and these results were in accordance with the findings of Mal et al 2006, Zhibing et al 2015.

Infiltration rate and bulk density of soil after harvest: Infiltration rate of soil showed significant variation among the treatments and results of the study indicated that the higher infiltration rate of 5.79 cm hr^{-1} was registered in mulching with dry leaves which was numerically superior over the other treatments. Mulching with paddy straw, grass, newspaper are in the next order of merit in improving the infiltration rate (Table 3). This was mainly attributed to rain drop interception by the crop canopy and mulching material under the treatment as a result of reduction in runoff and increased time of concentration coupled with prolific type of maize roots. Better growth of maize in these treatments besides porosity and mulching with dry leaves facilitated higher infiltration rate. These results are in complimentary with the findings of Adekalu et al 2007, Chaudhry et al 2004. Bulk density of the soil estimated after the harvest of the crop revealed that the significant differences among different treatments. However, numerically lower bulk density (1.43 g cc^{-1}) recorded by



*Date of harvest 27-12-2019 (Dry spell of > 25 days from the date of harvest)

Fig. 1. Effect of rainfall on soil moisture content (%) after harvest

Table 3. Effect of mulching method on physical properties of soil after harvest

Treatments	Infiltration rate (cm h^{-1})	Bulk density (g cc^{-1})
T_1	5.32	1.45
T_2	4.68	1.48
T_3	4.97	1.46
T_4	4.72	1.47
T_5	5.79	1.43
T_6	4.61	1.49
T_7	4.55	1.51
CD (p=0.05)	0.03	0.003

mulching with dry leaves followed by mulching with paddy straw(1.45 g cc^{-1}) and mulching with grass(1.46 g cc^{-1}). The higher bulk density of 1.51 g cc^{-1} was noticed in the control plot (Table 3). The reason for lower bulk density compared to initial bulk density might be due to addition of organic matter through incorporation of mulched material such as with dry leaves and paddy straw which add more organic carbon to soil may enhanced slightly higher and may also due to the additional organic matter incorporation may increases the soil porosity because of more micro pores in soil loose and consequently leads to lower bulk density. Similar results were also noticed by (Sharma et al 2009, Singh et al 2010).

CONCLUSION

The climatic parameters *viz*., rainfall, temperature, soil moisture and sunshine hours are most important for crop growth, development and to maintain sustainable crop yield. Rainfall is the most important climatic parameter among other factors and moisture deficit at critical stages of the crop growth in rainfed crop may result in drastic reduction in growth and yield of crop. Hence, the moisture conservation practices in dry farming may help in enhancing maize yield and low-cost mulching technique for moisture conservation. From the investigation it can be inferred that, introduction of mulching with dry leaves in maize was imposed at 30 days after sowing found not only superior with respect to soil moisture conservation, yield and economic returns but also it influences overall improvement soil physical properties and to sustain the crop yield under dryland condition.

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Effect of Integrated Nutrient Sources on Agronomic Performance of Onion (*Onion cepa* L.) and Soil Properties

Balvir Kaur, A.K. Boparai and Kuldeep Singh
Krishi Vigyan Kendra, Jalandhar-144 039, India
E-mail: Usha29@pau.edu

***Abstract*:** A field experiment was conducted to study the effect of integrated nutrient management in onion for two years at Krishi Vigyan Kendra, Jalandhar. The different combinations of farmyard manure, vermicompost and poultry manure along with inorganic fertilizers were used to evaluate the performance of onion. The maximum plant height, number of leaves, neck thickness, bulb weight and fresh bulb yield was in treatment with Farmyard manure @ 20 tones + Vermicompost @ 5 tones + Poultry manure @ 2 tones +100 % of recommended NPK was applied followed by farmyard manure @50 tones +100% recommended NPK (37.5t ha^{-1}) and Poultry manure @ 7.5 tones + Biofertilizer + 75 % of recommended NPK (35.7 t ha^{-1}). This study concluded that the integrated application of manures and chemical fertilizers is a must for improving soil nutrient status and nutrient use efficiency and ultimately enhances nutritional security.

Keywords: Onion, Yield, Organic, inorganic, Soil properties

Onion (*Allium cepa* L.) belongs to family *Alliaceas*, is a bulbous biennial herb which is most important vegetable cum condiments, spice crops demanded worldwide. India is the second largest producer of onion in the world, next to China with an area of 1.31 million ha with a production of 22.1 million tones ha^{-1} (FAOSTAT 2018) but the productivity is low 16.87 tones ha^{-1} as compared to other countries. Intensive cropping, imbalanced fertilization, minimal usage of micro nutrients and limited application of organic manures have resulted in the depletion of soil fertility could have resulted in low productivity and quality of the crop.

Onion shows significant response to organic and inorganic fertilizers (Soleymani and Shahrajabian 2012). Therefore, the usage of organic manures as alternative source of nitrogen would give better result in its growth and yield .Organic material, such as farmyard manure improves soil physico-chemical properties that are important for plant growth (Kidanu 2017). Decomposition of materials would provide additional nutrients to the growing medium which may lead to higher uptake of nutrient by the crop and subsequently high yield. Besides, organic manures have positive effect on root growth by improving the root rhizosphere conditions (structure, humidity, etc.) and also plant growth is encouraged by increasing the population of microorganisms (Shaheen et al 2007). A part from this, Organic manures enhance the different properties of soil i.e. physical, chemical and biological and also increase the moisture holding capacity of soil which resulted more in maintaining the quality of crop production and crop production (Dauda et al 2008). Organic manure and biofertilizers mixture increased the yield and provide more nutrients to onion tuber (Shaheen et al 2007) Cultivation of this nutrient responsive crop using eco-friendly innovative techniques like integrated use of organic manures along with inorganic fertilizer for sustainable use of available resources could be best way to increase production level. Keeping above in view an On Farm Trial (OFT) was conducted at Krishi Vighan Kendra, Jalandhar to study the effect of organic and inorganic Fertilizer on economic characters of crops as well as on soil properties.

MATERIAL AND METHODS

The On Farm Trial (OFT) was conducted at Krishi Vighan Kendra, Jalandhar to study the effect organic and inorganic fertilizers on economic characters of onion and soil properties during the year 2018 and 2019 in *Rabi* season. Krishi Vigyan Kendra, Nurmahal, Jalandhar is geographically situated at 31°09'N latitude, 75°59' E longitude and at an altitude of about 237 m above mean sea level. The climate of the region is extremely hot during the summer and cold during winter. The soil samples were collected from 0-15 cm depth before start of the experiment to determine the basic physical and chemical soil properties. The soil of the experimental site was sandy loam in texture having pH 7.84, EC. 0.24 ds/m, low in organic carbon content (0.41%), low in available N (94.6 kg ha^{-1}), high in available P_2O_5 (23.7 kg ha^{-1}) and medium in available K_2O (242.5 kg ha^{-1}). The experiment was laid in complete randomized block design replicated thrice. The experiment consists of six treatment combinations of organic and inorganic fertilizers viz. T_1- Farmyard manure @ 50 tones + Bio-fertilizer + 75 % of recommended NPK (75:37.5:37.5), T_2-Poultry manure @ 7.5 tones + Biofertilizer +75% of recommended NPK (75:37.5:37.5), T_3-Vermicompost @ 15tones + Bio-fertilizer + 75% of recommended NPK (75:37.5:37.5), T_4- Farmyard manure @ 20 tones + Vermi-compost @ 5 tones + Poultry manure@ 2 tones +100 % of recommended NPK (100:50:50), T_5-Farmyard manure @ 50+ tones +100% recommended NPK (100:50:50), T_6- 100% recommended NPK (100:50:50), T_7- Control.

Organic manures were mixed in the soil fifteen days prior to the transplanting of the onion. The chemical composition of organic manures is given in Table 1. The nursery of onion (cv. Punjab Naroya) was sown on raised beds using seed rate 10 kg ha^{-1} in last week of October. The transplanting was done in first fortnight of January in both the years following 15x7.5cm row to row and plant to plant spacing. Farmyard maures, vermi-compost and poultry manure were added 15 days prior to transplanting .The inorganic fertilizer sources used were urea for N (46% N), diammonium phosphate for P (18 % N and 46 % P2O5), muriate of potash for K (60% K2O). Full dose of phosphorus, potash, half nitrogen was applied before transplanting. The remaining dose of nitrogen was top dressed after one month of transplanting. The 10 kg of *consortium* bio-fertilizer per hectare was mixed with 25 kg of soil and was broadcasted before transplanting. All other practices of cultivation were followed as recommended by Punjab Agricultural University, Ludhiana (Anonymous 2018).

The uprooting of the bulbs was done manually in the first week of May during *Rabi* 2018 and last week April during *Rabi* 2019. After harvesting, the bulbs were cured and then leaves were cut 1-2 cm above the neck and bulb yield was recorded. Data on plant height (cm), leaves /plant (No.), neck thickness (mm),fresh bulb weight(g), fresh bulb yield (ton ha^{-1}). Data on growth and yield parameters were recorded from ten randomly selected plants from each plot. The data collected on various parameters under study were statistically analyzed with CPCS1 software

Analysis of soil samples: The soil samples from 0-15 cm depth were randomly collected at five places in each plot after the end of the experiment and determined for soil physical and chemical properties using standard procedures. Bulk density was determined by calculating the soil's dry weight (dried at 110°C) and volume of the soil sample. The pH of the soil samples were measured using 1:2 ratio of soil and water suspension (Jackson 1973) and electrical conductivity (EC) was determined using a soil–water supernatant in a 1:2 ratio (Richard 1954). The organic carbon was determined using the wet combustion method (Walkley and Black 1934). The available nitrogen was estimated using alkaline permanganate method (Subbiah and Asija 1956). Soil was analyzed for available potassium by extracting it with neutral ammonium acetate solution (Merwin and Peech 1950) and available phosphorous following the method of Olsen et al (1954).

RESULTS AND DISCUSSION

Effect on yield and yield attributes: The yield and yield attributes of onion also showed a significant variations among all the treatments (Table 2). A significant variation was observed in plant height (cm) of rabi onion due to application of organic and inorganic sources which varied from 35.6cm to 70.5cmwith average mean value of 60.0.The maximum number of leaves per plants was recorded higher in T_4 (7.8) followed by T_5 and T_3 which was at par with T_2. Minimum number of leaves was in T_7 (3.4) There was significant difference o in neck thickness with maximum neck in T_4(11.0) which was at par with T_5 followed by T_3 and T_3. Minimum neck thickness was ind T_7(5.0) followed by T_6(9.2).

Bulb yield (g) showed significant difference among all the treatment of inorganic and organic fertilizer which varied from 34.2 g-92.5 g with geometric mean of 76.4. Maximum Bulb yield was recorded in by T_4 where we applied Farmyard manure @ 50 tones + Vermicompost @ 5 tones + Poultry manure @ 2 tones + 100 % of recommended NPK , Minimum bulb weight (g) was recorded in T_7(34.2) Fresh bulb yield ton ha^{-1} was recorded significant difference among all treatment in this experiment . Maximum fresh bulb yield (ton

Table 1. Moisture and nutrient contents of organic manures

Organic manure	Moisture content (%)	Total nutrient content						
		%			mg kg^{-1}			
		N	P	K	Fe	Zn	Mn	Cu
Farmyard manure	61	1.92	0.72	2.15	550.3	120.3	193.8	69.8
Poultry manure	48	2.53	1.95	2.31	514.2	141.8	410.5	83.2
Vermicompost	53	2.05	0.95	2.12	590.8	107.9	313.6	53.8

/ha^{-1}) was recorded in T_4 followed by T_5, T_2, T_3 which was at par with T_1. Minimum bulb yield was recorded by T_7 (16.4). It was also revealed that bulb weight and bulb yield was directly correlated. Gebremichael et al 2017also concluded that the application of organic fertilizer along with inorganic fertilizer (nitrogen) increased onion yield, shelf life and soil fertility replenishment. Results were also in line with Saima Sultana (2014), Brar et al (2015) and Ali et al (2018)

Effect of integrated nutrient management on soil properties: The application of organic manures affected the soil properties significantly (Table 3). The bulk density of soil decreases significantly from initial value of 1.42 Mg m^{-3} to 1.22 Mg m^{-3} where FYM and 100% recommended fertilizers (T_5) were applied closely followed by combined application of organic manures in other treatments. It is mainly due to the application of organic manures which increases the pore capacity of the soils and reduces the bulk density (Gopinath and Mina 2011). Soil pH varied significantly with the treatments and it decreased with organic manures application and combined application but increased with only chemical fertilizer application (Table 3). The slight decrease in soil pH is due to the release of organic acids during the decomposition of organic manures The result are supported by the findings of Dhiman et al (2019) and Randhawa et al (2021). The EC of the soil samples increased non-significantly with the application of organic manures. The decomposition of organic manures released acids or acid-forming compounds that react with sparingly soluble salts already present in the soil and either converted them into soluble salts or at least increased their solubility (Sarwar et al

Table 2. Effect of integrated nutrient sources on growth parameter and yield (Pooled data of two years)

Treatment/	Plant height (cm)	Leaves/ plant (No.)	Neck thickness (mm)	Bulb weight (g)	Fresh bulb yield (ton ha^{-1})
T_1- Farmyard manure @ 50 tones + Bio-ferlilizer +75 % of recommended NPK (75:37.5:37.5)	63.7	6.9	10.2	83.0	34.3
T_2-Poultry manure @ 7.5 tones + Biofertilizer +75% of recommended NPK (75:37.5:37.5)	65.3	7.6	10.3	85.9	35.7
T_3-Vermicompost @ 15 tones + Bio-fertilizer + 75% of recommended NPK (75:37.5:37.5)	64.6	7.6	10.7	83.6	34.8
T_4- Farmyard manure @ 20 tones + Vermi-compost @ 5 tones + Poultry manure @ 2 tones +100 % of recommended NPK (100:50:50)	70.5	7.8	11.0	92.5	38.9
T_5-Farmyard manure @ 50+ tones +100% recommended NPK (100:50:50)	70.2	7.7	10.9	90.9	37.5
T_6- 100% recommended NPK (100:50:50)	50.6	6.5	9.2	65.3	31.4
T_7- Control	35.6	3.4	5.0	34.2	16.4
Mean	60.0	6.7	9.5	76.4	32.4
CD (P=0.05)	2.5	1.1	1.2	2.0	2.56

Table 3. Effect of different treatments on soil properties after two years

Organic manure	BD (Mg m^{-3})	pH	EC	Organic C (%)	Total nutrient content (%)		
					N	P	K
T_1- Farmyard manure @ 50 tones + Bio-ferlilizer +75 % of recommended NPK (75:37.5:37.5)	1.23	7.69	0.43	0.51	142.3	29.4	342.9
T_2-Poultry manure @ 7.5 tones + Biofertilizer +75% of recommended NPK (75:37.5:37.5)	1.32	7.73	0.39	0.47	132.7	35.4	356.4
T_3-Vermicompost @ 15 tones + Bio-fertilizer + 75% of recommended NPK (75:37.5:37.5)	1.29	7.72	0.36	0.48	138.5	27.4	337.6
T_4- Farmyard manure @ 20 tones + Vermi-compost @ 5 tones + Poultry manure @ 2 tones +100 % of recommended NPK (100:50:50)	1.25	7.82	0.42	0.49	141.8	32.1	339.7
T_5-Farmyard manure @ 50+ tones +100% recommended NPK (100:50:50)	1.22	7.68	0.41	0.50	129.3	28.3	329.2
T_6- 100% recommended NPK (100:50:50)	1.38	7.89	0.30	0.43	128.5	27.4	310.1
T_7- Control	1.40	7.83	0.24	0.41	92.8	21.3	258.4
CD (P=0.05)	0.14	0.15	NS	0.03	3.54	1.34	2.76

2008). There was a significant increase in organic carbon in all the treatment except the control and where only inorganic fertilizers were applied after the period of two years. Application of FYM resulted in highest increase in organic carbon (0.51%) along with the inorganic fertilizers as compared to control. The higher increase in OC content due to combined applications of manures and fertilizers may be because of better crop growth accompanied by higher root biomass generation and higher return of leftover plant residues (Mohana et al 2016). The available N, P and K were higher in integrated nutrient management as compared to control.The result might be due to improvement of other physical and chemical properties for organic manure application compared to the chemical fertilizer application.The highest N content (142.3 kg ha^{-1}) was observed where FYM was applied along with the inorganic fertilizers and biofertilizer. The highest P content (35.4 kg ha^{-1}) was in treatment where poultry manure was applied. This is due to the higher content of initial P in poultry manure as compared to other FYM and VC.The higher availability of phosphorus in manure-amended treatments might have been attributed to the solubilization of P by organic acids released during the decomposition of organic manures, organic materials can reduce the P-sorption capacity of the soil, enhance P availability, improve Recovery or result in better utilization by and due to a reduction in P fixation in soil with chelation of P fixing cations (Fe and Al) (Rathod et al 2013). The higher content of available K in treatments in which organic manures were added could be due to the addition of K through manures that could supply a certain amount of K in soil through the interaction of organic matter with clay. The results are in agreement with the findings of Mazumdar (2014) and Sathish et al(2011).The release of N, P and K was higher in T_1 where biofertilizer was applied along with the FYM as compared to T_5 where only FYM was applied..Some of the organic substances released during the mineralization may act as chelates that help in the absorption of iron and other micro-nutrients(Petrovic and Pokluda,2020). The results suggested that the integrated nutrient management not only results in higher yield but also significantly affects the soil health as compared to the application of inorganic fertilizers only. Due to improved soil properties it enables the roots to grow deeper ensuring strong stems and taller plants.

CONCLUSIONS

The results reported that the use of farmyard manure @20 tones +Vermi-compost@ 5 tones + Poultry manure@ 2 tones +100 % of recommended NPK(100:50:50)gave the maximum plant height, number of leaves ,neck thickness, bulb weight and yield as compared to other treatments. The organic manures also have positive effect on improving the soil organic carbon, pH, EC and nutrient content (N, P and K) of the soil. The application of organic manures improves the bulk density of soil significantly which helps in higher yield of the root crops. These results suggested that a certain combination of organic and inorganic fertilizers is equally important for obtaining higher yields. It can be concluded that the integrated nutrient management is important than the sole use of inorganic fertilizers which indicates the improved nutrient use efficiency with the aid of organic manures.

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Soil Fertility Status and Nutrient Uptake Pattern in Fodder Maize and Ricebean Intercropping at Varying Nutrient Levels

V. Rundan, Magan Singh, B.R Praveen and M. Bhargava Narasimha Yadav[1]

Agronomy Section, ICAR-National Dairy Research Institute Karnal-132 001, India
[1]Department of Soil Science and Agricultural Chemistry, UAS, Dharwad-580 005, India
E-mail: rundangowda10@gmail.com

Abstract: Sustaining soil fertility and enhancing fodder production on smallholder farms is a great challenge in the trans-gangetic plain (North-Western zone of Haryana state). Therefore, the present investigation on the effect of nutrient management practices on fodder maize and ricebean intercropping under irrigated conditions was conducted during the rainy season of 2019 at the ICAR-NDRI, Karnal. The experiment was laid out in a randomised block design with 14 treatments. The higher value of total fresh fodder (45.25 t ha^{-1}) and dry matter yield (10.93 t ha^{-1}) in maize + ricebean intercropping system in a 1:1 row ratio with 100% RDF and Plant growth promoting rhizobacteria (PGPR). The composition of macronutrient (N, P, K) and micronutrient (Zn, Cu, Fe, and Mn) content along with uptake significantly improved under sole treatments, but it is comparable with 1:1 and 2:1 ratios receiving RDF + PGPR. The maximum total uptake was recorded in Maize + Ricebean (1:1) + 100% RDF + PGPR. Soil parameters such as pH, EC, organic carbon, available P and K content were not affected significantly. But significantly higher available N was in the sole ricebean plot and some intercropped plots receiving 100% RDF in both 1:1 and 2:1 ratio. The treatment of maize + ricebean (1:1) + 100% RDF + PGPR treatment enriched green and dry fodder yields with the fulfilment of qualitative fodder production along with maintaining the soil fertility.

Keywords: Fodder maize, Ricebean, Intercropping, Nutrient content, Uptake

Maize (*Zea mays* L.) is the most important *kharif* fodder, which is grown over 0.9 Mha in various parts of the country. Globally, maize is grown in an area of about 150 Mha with a production of 1134 MT as a grain purpose. It is grown on 9.5 Mha in India, with a production of 28.7 MT in 2019-20 (Anonymous 2020). It can be grown in both temperate and tropical regions, from mean sea- level up to an altitude of 3000 m. Due to its high yielding potential, along with good quality fodder and an absence of anti-nutritional factors, it is considered the most preferable fodder crop among farmers (Arya et al 2015). It is also an excellent fodder crop for silage making due to its low protein content and the presence of more water-soluble carbohydrates. This makes it less resistant to pH change in the silage making process. Because of its photo-insensitive nature, this crop can grow all year long. Basically, maize is a photosynthetically C_4 type plant which is capable of utilizing water efficiently and can also be grown in an area receiving an annual rainfall of 50 cm, but an optimum rainfall of 120-150 cm is necessary for a higher yield. Maize is a highly nutrient-exhaustive crop and demands more nutrients from the soil (Ciampitti and Vyn 2014). Further, to sustain the productivity of maize, proper nutrient management practices like applying fertilizers, manure and biofertilizers including PGPR, along with suitable intercropping with legumes and crop rotation, help to maintain soil fertility to some extent. Ricebean [*Vigna umbellate* (Thub.)] is one of the underutilized leguminous fodder crops which is grown in western, northern and eastern India in an area of around 20,000 ha (Katoch 2013). It is a neglected crop grown under diverse climatic conditions, from tropical to temperate, without the addition of any inputs. It can be grown as an intercrop in different cereal based cropping systems like maize, sorghum, bajra etc. Ricebean has an erect to semi erect growth habit. Some varieties have a twining growth habit, which makes them most suitable to grow along with maize. Due to intensive cultivation year after year without the addition of proper organic matter to the soil, the organic carbon content of the soil is depleted. The majority of our Indian soils are low in available nitrogen, low to medium in phosphorus and medium to high in available potash, which results in a negative soil nutrient balance (Kumar et al 2018). In addition to macro nutrient deficiency, there is another problem of micro nutrient deficiency due to intensive cultivation with the use of straight and high-analysis fertilizers (Singh 2008). An adequate supply of nutrients from both organic and inorganic sources in combination with biofertilizer and PGPR is very important to fulfil the nutrient demand of fodder crops. Fodder production through scientific crop rotation, cropping systems/intercropping with cereals and legumes helps in enhancing the total productivity as well as improving the quality of fodder along with maintaining soil nutrient status in a sustainable manner. The present study was, therefore, designed to find out the nutrient management practices for maximization of green fodder yield, nutrient content and nutrient uptake in fodder maize and ricebean intercropping under irrigated conditions.

MATERIAL AND METHODS

Site details: Agronomic experiment was performed at ICAR-NDRI, Karnal during rainy season of 2019. Geographically, the experimental site situated at 29°45' N latitude, 76°58' E longitude and at an altitude of 245 m above mean sea level (MSL).

Soil status: The soil of experimental site was neutral in pH (7.24), clay loam in texture, medium in organic carbon (0.62%), low in available N (147.4 kg ha^{-1}) and medium in available P (24.5 kg ha^{-1}) and K (251.2 kg ha^{-1}).

Treatment details: The experiment was laid out in Randomized Block Design with 14 treatments (Table 1). For sole crops their respective recommended dose of fertilizer was applied whereas, in intercropping we consider the demand of only main crop (maize) and fertilizer varied as per the treatments (100%, 75% and 50% RDF). The maize seeds were treated with PGPR inoculums by diluting 50 ml of PGPR solution in 1 liter of water and seeds were soaked overnight, dried in the shade before sowing in the field. The fodder maize (Cultivar J-1006) and Ricebean (Sikkim local) were sown with seed rate of 45 and 35 kg/ha during 1st week of August by giving spacing of 30 × 10 cm for sole crop of maize and ricebean. The intercropped maize geometry was modified by giving spacing of 45 × 7.5 cm to introduce ricebean. For accommodating component crops in intercropping treatments additive series was used.

Forage analysis: To estimate the nutrients (macro and micro), plant samples collected at harvest were oven dried (65–70°C), grinded, and passed through a sieve (pore size of 2 mm). The nitrogen content in plant samples of maize was estimated by a modified Micro Kjeldahl method (Piper 1966). Phosphorus and potassium contents were determined in the Di-acid extracts after digesting the plant material with Di-acid mixture of 9:4 (HNO_3: $HClO_4$) (Piper 1966). The phosphorus content in the plant sample was determined by the Vanado-molybdo phosphoric yellow colour method using a spectrophotometer (Jackson 1973) and potassium content was determined using a flame photometer (Piper 1966). After digestion on the hot plate, the plant samples were analyzed for micronutrient content using an Atomic Absorption Spectrophotometer (Lindsay and Norvell 1978).

Statistical analysis: All the data recorded were processed in Microsoft excel 2010 and analyzed with ANOVA at 5% level of significance.

RESULTS AND DISCUSSION

Forage yield (GFY & DMY): Dry matter and green fodder yield were significantly influenced by different nutrient

Table 1. Effect of nutrient management practices on green fodder and dry matter yield in fodder maize + ricebean intercropping

Treatments	Green fodder yield (t ha^{-1})			Dry matter yield (t ha^{-1})		
	M	R	Total	M	R	Total
T_1- Maize + RDF	34.17	-	34.17	8.51	-	8.51
T_2- Ricebean + RDF	-	15.17	15.17	-	3.57	3.57
T_3- M + R (1:1) + RDF	31.07	13.02	44.08	7.50	3.01	10.51
T_4- M + R (1:1) + 50% RDF	26.40	10.10	36.50	5.84	2.06	7.90
T_5- M + R (1:1) + 50% RDF + PGPR	27.62	10.05	37.67	6.22	2.15	8.37
T_6- M + R (1:1) + 75% RDF	30.17	12.00	42.17	6.87	2.74	9.61
T_7- M + R (1:1) + 75% RDF + PGPR	29.67	12.52	42.00	6.81	2.88	9.69
T_8- M + R (1:1) + 100% RDF + PGPR	32.00	13.25	45.25	7.85	3.07	10.92
T_9- M + R (2:1) + RDF	32.08	8.25	40.33	7.78	1.10	8.88
T_{10}- M + R (2:1) + 50% RDF	27.00	7.33	34.33	5.95	1.67	7.62
T_{11}- M + R (2:1) + 50% RDF + PGPR	27.83	7.17	35.00	6.34	1.64	7.98
T_{12}- M + R (2:1) + 75% RDF	31.15	7.48	38.63	7.41	1.74	9.15
T_{13}- M + R (2:1) + 75% RDF + PGPR	31.20	7.47	38.67	7.51	1.72	9.23
T_{14}- M + R (2:1) + 100% RDF + PGPR	31.92	8.58	40.50	7.95	1.99	9.94
CD (p=0.05)	3.92	1.82	4.11	1.09	0.40	1.12

— Maize; R- Ricebean; RDF- Recommended dose of fertilizer; PGPR- Plant growth promoting rhizobacteria management practices (Table 1). Intercropping of maize with ricebean in a 1:1 ratio with RDF + PGPR records higher green fodder (45.25 t ha^{-1}) and dry matter yield (10.93 t ha^{-1}) in comparison to sole maize and ricebean. Further, the contribution of both the crop was less than 100% in comparison with the sole crop (100%). This is due to the partition of available resources among both the crops under intercropped cultivation. However, the relative yield was found to be superior in intercropped conditions, especially by sowing maize and ricebean in a 1:1 ratio with RDF and PGPR this may be due to an increase in the photosynthetic area leading to more uptake of nutrients, which in turn increases biomass production. The extra yield contribution from ricebean in the 1:1 additive series eventually increases the fodder yield. Further increases in fertilizer dose has a positive effect on other growth attributes which are directly correlated with green fodder yield. The results are in tune with Zaman and Malik (2000) and Kheroar and Patra (2013).

Macro nutrient content and uptake: The higher N, P and K content was recorded in the sole maize treatment (1.43% N, 0.3% P and 0.9% K) (Table 2). In ricebean, only N content showed a significant difference among various nutrient management practices. Higher N content in ricebean forage was analyzed in sole ricebean + RDF (3.03% N). In P and K content, no significant influence was observed among various nutrient management practices. In terms of total N, P and K uptake per plot basis was significantly higher under intercropped condition with Maize + Ricebean (1:1) + 100% RDF + PGPR ie., 199 kg N ha^{-1}, 35.30 kg P ha^{-1}, 116.09 kg K ha^{-1}) respectively. Significantly higher N, P, and K content and uptake was in treatments that received full doses of fertilizer. This might be due to a higher uptake of nutrients. Even in some of the treatments under intercropped situations where they had received 100% RDF, also recorded higher values of N, P and K content and uptake. This might be due to no competition for available nutrients and also some nitrogen fixed by the ricebean crop, helping the component crops to overcome their nitrogen shortage. However, as fertilizer dose decreases, the nutrient content of both maize and ricebean decreases, but the difference is not huge because of increased nodule numbers, which increase the N-fixing ability of ricebean. Sharma and Gupta (2002) also observed the same trend in pearl millet and cluster bean intercropping.

Micronutrient content and uptake: There were significant differences among the different treatments and higher zinc (44.5 ppm), iron (429 ppm), manganese (41.73 ppm) and copper content (15.47 ppm) was in maize with 100% RDF in comparison with other treatments (Table 3). Nutrient management has significant influence on minerals viz. Zn content and no significant difference was found in Fe, Mn and Cu content in ricebean plants on a dry weight basis. However, Zn (57.7 ppm), Fe (487 ppm), Mn (84.2 ppm) and Cu (22.5 ppm) content was higher in ricebean monoculture. Even though higher micronutrient content was in both sole maize and ricebean plots, higher uptake of Zn (508.85 g ha^{-1}), Fe (4586.92 g ha^{-1}), Mn (572.80 g ha^{-1}) and Cu (185.93 g ha^{-1}) was

Table 2. Effect of nutrient management on macronutrient content and uptake pattern in fodder maize + ricebean intercropping

Treatments	N content (%)		P content (%)		K content (%)		Total uptake (kg ha^{-1})		
	M	R	M	R	M	R	N	P	K
T_1	1.43	-	0.30	-	0.90	-	121.84	25.35	76.44
T_2	-	3.03	-	0.48	-	1.65	107.88	16.93	58.94
T_3	1.40	2.89	0.28	0.41	0.87	1.53	192.07	33.43	111.43
T_4	1.22	2.72	0.23	0.38	0.71	1.34	127.32	21.43	69.08
T_5	1.27	2.74	0.25	0.38	0.71	1.41	137.76	23.79	74.81
T_6	1.34	2.81	0.26	0.39	0.76	1.47	169.16	28.72	92.34
T_7	1.37	2.81	0.26	0.40	0.79	1.48	173.75	29.42	95.39
T_8	1.40	2.90	0.29	0.41	0.88	1.53	199.00	35.30	116.09
T_9	1.41	2.92	0.29	0.42	0.88	1.58	165.57	30.80	98.39
T_{10}	1.28	2.77	0.25	0.39	0.75	1.41	122.20	21.34	67.97
T_{11}	1.29	2.77	0.26	0.39	0.75	1.46	126.86	22.97	71.34
T_{12}	1.38	2.85	0.27	0.40	0.83	1.48	152.59	27.04	87.18
T_{13}	1.39	2.87	0.27	0.40	0.87	1.50	153.70	27.28	91.28
T_{14}	1.41	2.92	0.29	0.44	0.90	1.65	170.45	31.94	103.95
CD (p=0.05)	0.13	0.16	0.03	NS	0.08	NS	23.21	5.11	12.61

See Table1 for treatment details

observed in intercropped conditions, i.e., sowing maize and ricebean in a 1:1 ratio with application of 100% RDF and PGPR. This might be due to the higher photosynthetic area available to harness sunlight, which led to an increase in the biomass yield and uptake of nutrients under an additive series of intercropping. Higher micronutrient concentration in both maize and ricebean was recorded under sole crop conditions than intercropping because the sole crop experienced zero competition from intercrop for available resources, which made the plant grow healthier than in intercropped conditions. The results are to the tune of Surve et al (2012).

Soil chemical properties: The soil analyses result indicated that there was no substantial change in the chemical properties of soil like pH, EC and organic carbon content (Table 4). However, higher pH was in Maize + Ricebean (2:1) + 75% RDF + PGPR (7.42). In EC initial soil status was high but after completion of experiment its value was little lowered. However, higher value of EC was noticed in Maize + Ricebean (2:1) + 50% RDF (0.225 ds/m). Even in soil organic carbon content there was slight decreased after completion of experiment but not in significant amount. Higher organic carbon recorded in sole ricebean plot (0.62) this might be due to higher root biomass and higher nodulation in sole ricebean plot. The result of organic carbon was in line with observation made by Girijesh et al (2017). Further the experiment was carried over for short period of time and those properties changes over long period of time with similar practices (Ranpariya et al 2017).

There was a significant change only in soil available N content, but there was no variation observed in soil P or K content before and after the completion of the experiment (Table 4). The higher value of available N was recognized in the sole ricebean + RDF plot (150.73 kg ha^{-1}), but was statistically at par with T_3, T_8, T_9, and T_{14} treatments. The lower N was analyzed in the sole maize plot (130.33 kg ha^{-1}). The higher value of available N in the sole ricebean plot might be due to higher atmospheric nitrogen fixation by the ricebean crop compared to sole maize. Hirpa (2014) also observed the same trend in maize and haricot bean. There was no significant variation in both available P and K content by various nutrient management practices, but a higher value of both P and K was under intercropped conditions. The highest available P was recorded in the maize + ricebean (1:1) + 100% RDF plot (26.68 kg ha^{-1}) and the lowest value was in the sole maize plot (23.29 kg ha^{-1}). In available K, a higher value was recorded in the sole ricebean plot (244.37 kg ha^{-1}) and a lower value was in the sole maize plot (221 kg ha^{-1}). The lower values of P and K in pure maize may be due to the exhaustive nature of maize for available nutrients. Dahmardeh et al (2010) and Patel et al (2017) observed the same trend in various legume and cereal based intercropping. The micronutrient content, especially Zn and Fe, varied significantly among the different treatments, with no significant variation in Mn and Cu content. The Zn and Fe content were initially high but slightly decreased after the completion of the experiment. The greater value of Zn (0.99

Table 3. Effect of nutrient management on micronutrient content in fodder maize + ricebean intercropping

Treatments	Zn content (ppm)		Fe content (ppm)		Mn content (ppm)		Cu content (ppm)		Total uptake (g ha^{-1})			
	M	R	M	R	M	R	M	R	Zn	Fe	Mn	Cu
T_1	44.5	-	429	-	41.73	-	15.47	-	367.25	3648.95	355.48	131.51
T_2	-	57.7	-	484	-	84.20	-	22.50	200.38	1690.23	299.95	80.09
T_3	43.2	55.3	410	450	39.75	83.00	15.27	22.33	505.72	4457.90	548.32	182.16
T_4	38.5	50.7	373	404	36.30	81.30	13.50	21.24	329.52	3013.26	380.16	122.88
T_5	38.2	50.0	380	430	36.33	81.20	13.58	21.33	346.53	3308.22	399.35	130.22
T_6	41.2	53.8	408	436	39.30	82.00	14.27	21.67	430.82	3994.66	494.34	157.35
T_7	40.7	53.0	385	435	40.21	82.30	14.43	21.47	430.24	3882.68	509.64	160.20
T_8	43.0	56.3	415	470	40.65	82.70	15.00	22.17	508.85	4586.92	572.80	185.93
T_9	42.5	55.7	425	450	41.43	83.20	15.17	22.00	437.63	4167.53	482.40	159.98
T_{10}	40.2	52.3	382	417	34.50	80.70	13.53	21.03	326.39	2964.66	339.99	115.42
T_{11}	40.2	53.2	378	423	36.23	81.00	13.87	21.43	342.51	3085.18	362.53	122.79
T_{12}	41.0	53.0	403	436	38.33	81.70	14.50	21.60	396.43	3737.46	425.40	145.16
T_{13}	41.9	54.4	406	437	37.00	81.80	14.93	21.83	408.40	3802.08	418.96	149.65
T_{14}	43.7	56.0	434	471	41.21	83.80	15.37	22.37	458.27	4407.46	493.24	166.53
CD (p=0.05)	3.67	4.39	40.78	NS	4.67	NS	1.21	NS	61.66	490.53	64.21	21.64

See Table1 for treatment details

Table 4. Effect of nutrient management on soil chemical properties after harvest of fodder maize + ricebean intercropping

Treatments	Chemical properties			Available soil nutrient			Micro nutrient status (ppm)			
	pH_2	EC_2 (ds/m)	OC (%)	N	P	K	Zn	Fe	Mn	Cu
Initial status	7.24	0.227	0.62	147.40	25.70	251.20	0.99	9.67	9.54	0.86
T_1	7.37	0.220	0.56	130.33	21.29	221.00	0.69	8.47	8.45	0.77
T_2	7.30	0.218	0.62	150.73	22.69	244.37	0.72	7.85	9.71	0.81
T_3	7.32	0.219	0.61	146.53	24.68	240.43	0.95	9.53	9.29	0.91
T_4	7.20	0.210	0.57	130.48	21.48	225.43	0.75	7.36	8.50	0.85
T_5	7.38	0.222	0.60	140.12	23.85	235.17	0.79	8.45	9.16	0.83
T_6	7.29	0.213	0.58	132.65	23.43	228.63	0.88	8.18	8.66	0.88
T_7	7.23	0.211	0.59	135.24	23.95	232.33	0.70	7.54	9.07	0.85
T_8	7.13	0.206	0.60	146.95	24.64	246.03	0.74	7.62	9.33	0.83
T_9	7.31	0.219	0.59	143.08	24.55	238.63	0.92	9.04	9.23	0.84
T_{10}	7.41	0.225	0.57	133.59	24.43	229.80	0.97	9.09	8.52	0.87
T_{11}	7.28	0.212	0.58	131.32	22.40	226.03	0.93	7.62	8.64	0.82
T_{12}	7.36	0.219	0.58	139.91	23.68	236.00	0.99	9.46	8.68	0.83
T_{13}	7.42	0.224	0.60	137.20	23.77	233.33	0.80	9.18	9.11	0.89
T_{14}	7.41	0.223	0.61	148.96	24.60	243.47	0.74	9.05	9.21	0.91
CD (p=0.05)	NS	NS	NS	9.59	NS	NS	0.10	0.85	NS	NS

See Table1 for treatment details

ppm) was analyzed in the maize + ricebean (2:1) + 75% RDF treatment and the lower value of Zn was noticed in the sole maize plot. In Fe, the maximum was recorded in maize + ricebean (1:1) + RDF (9.53 ppm) and a lower value in maize + ricebean (1:1) + 50% RDF treatment (7.36 ppm). Although Mn and Cu content showed no significant difference among various treatments, a higher value of Mn was in sole ricebean + RDF (9.71 ppm) whereas, in Cu, a higher value was in maize + ricebean (1:1) + RDF plot and maize + ricebean (2:1) + 100% RDF + PGPR (0.91 ppm) respectively.

CONCLUSION

Among the different nutrient management practices, combined application of 100% RDF and PGPR in maize + ricebean (1:1) intercropping significantly increased fodder yield, macro and micro-nutrient content with grater uptake, which eventually indicated the fulfilment of qualitative fodder production and was found to be advantageous to the growers along with improving the soil fertility.

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Carbon Sequestration and Associated Soil Enzymatic Activities as Influenced by Long-Term Fertilizers and Manure Application under Rice-Wheat Cropping System

Mohammad Yaseen, K.P. Raverkar[1], Ramesh Chandra[1], Navneet Pareek[1] and D.K. Singh[2]

Faculty of Agricultural Sciences, GLA University, Mathura-281 406, India
[1]Department of Soil Science, [2]Department of Agronomy
College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar-263 145, India
E-mail: yaseenkhanagri@gmail.com

Abstract: An investigation was undertaken to study 30 years fertilization impact on total soil organic carbon (TOC), C sequestration, soil enzymatic activities and yield of rice in Aquic Hapludoll under rice-wheat sequence in sub-humid and sub-tropic of India. The experiment comprised 14 treatments having N, P, K levels with or without FYM and Zn. At inception of experiment (1984) TOC was 12.18 g kg^{-1} and highest (15.64, 13.26, 11.56 g kg^{-1}) was observed with super optimal NPK (180:80:40)+Zn+FYM which was at par to optimal/100 % NPK (120:40:40)+Zn+FYM in 0-15, 15-30 and 30-60 cm soil depth. In 0-15 cm soil layer the highest and lowest C sequestration was found in 100 % NPK+Zn+FYM and 100 % N, respectively. Application of super optimal and optimal NPK in conjunction with FYM and Zn recorded maximum fluorescein diacetate activity (FDA) and β-glucosidase activity in 0-60 cm soil profile. Highest grain yield of rice found due to application of 100 % NPK+Zn+FYM. Therefore, from this experiment, it is concluded that integration of FYM and Zn with super optimal and optimal NPK are most efficient nutrient management practices in improving soil health and production of rice-wheat cropping system by sequestering more C and improving C associated enzymatic activities in soil.

Keywords: Long-term fertilization, Carbon sequestration, Fluorescein diacetate activity, β-glucosidase activity, Rice-wheat cropping system

Agricultural soil has dual nature as it also serves as a potential sink for atmospheric C as SOC, which contributes to improve productivity and quality (Rudrappa et al 2006, Kundu et al 2007). Dynamics of organic C storage in agricultural soils affects global climatic change and crop productivity (Li et al 2007). The awareness of greenhouse gas emissions and concerns about the global warming have led to an increased interest in storing and sequestering C in soils (Banger et al 2009). For enhancing the C sequestration, there is critical need to develop best nutrient management practices. Previous studies showed that C sequestration potential is influenced by nutrient management, climate and soil conditions (Chabbi et al 2009), cropping systems (Jagadamma and Lal 2010) and fertilization (Bhattacharyya et al 2007). Soil and crop management practices like crop rotation, long-term fertilization and change in land-use pattern exert a considerable impact on soil physical (Bhatt et al 2017) and biological (Yaseen et al 2017) properties *vis-à-vis* soil carbon dynamics (Yaseen et al 2022) over time.

Long-term applications of inorganic fertilizer and manure is an essential component of soil management in arable crop production systems. These practices are used primarily to increase nutrient availability to plants and crop yields in agricultural production *vis-à-vis* maintains the soil organic matter (SOM), improve soil microbial and enzymatic activities that directly or indirectly affect soil fertility (Ferreras et al 2006, Nayak et al 2007). Therefore, it becomes pertinent to study the effect of various nutrient management practices on TOC and C sequestration to store excess amount of atmospheric CO_2. The present study was carried out with hypothesis that various nutrient management practices over a period of 30 years in Aquic Hapludoll under rice-wheat cropping system might be influenced distribution of TOC, C sequestration, flourescein diacetate activity (FDA), β-glucosidase activity and yield of rice. The results of investigation would lead to identify the most efficient nutrient management practices for C sequestration in sub-humid and sub-tropic of India.

MATERIAL AND METHODS

Experimental site: A long-term fertility experiment was established in 1984 at Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar (29° N, 79°3' E and 243.84 msl) Uttarakhand, India. Two crops per year wheat (*Triticum aestivum* L.) and rice (*Oriza sativa* L.) were cultivated. The region climatically was characterized by sub-humid and sub-tropical with hot and dry summer and cold winter. Temperatures are highest in May-June and lowest in December-January. An average total rainfall ranges from 1300-1500 mm per annum of which about 85-90 % is received from June to September. At start of experiment (1984) the silty loam soil contained 8.0 soil pH, 0.12 dS m^{-1} EC, 1.33 Mg m^{-3} bulk density, 2.1 % soil organic matter (SOM), 0.1% total nitrogen (N), 20 kg ha^{-1} available phosphorus (P) and 222 kg ha^{-1} available potassium (K).

Experimental design: The experiment comprises of 14 fertilization treatments (Table 1) replicated 4 times in randomized block design (RBD). During *kharif* season rice (*cv*. Pant Dhan 4) was sown every year during first week of June and harvested manually during first week of November and *rabi* season wheat (*cv.* UP 2425) was sown in November and harvested during third week of April at a fixed site with the same layout plan.

Collection of soil sample: Representative soil samples from 0-15, 15-30 and 30-60 cm depth were collected after the harvest of 30^{th} rice crop in 2014-15. The samples were divided into two parts before processing. One part was stored at 0-4°C for the assessment of enzymatic activities and other part was air dried under shade and sieved to analyze other properties of soil.

Soil analyses: Total soil organic carbon (TOC) was determined by wet oxidation followed by titration with ferrous ammonium sulphate (Walkley and Black, 1934) and bulk density by core sampler method listed by Blake (1965). The fluorescein diacetate activity (FDA) and *β*-glucosidase activity were determined by the method given by Green et al (2006) and Hayano (1973), respectively.

Data calculation: TOC stock, amount of C sequestration and C sequestration rate of profile for each of three depths was computed (Fan et al 2014).

TOC stock (Mg C ha^{-1}) = TOC ×D × BD ×10 ……..(1)

Where, TOC is total soil organic carbon concentration (g C kg^{-1}), D is soil depth (m), BD is bulk density (Mg m^{-3}) and 10 is a factor to adjust unit i.e., Mg m^2 to Mg ha^{-1}

Amount of C sequestration was calculated by subtracting the values of C stock at initial year of experimentation (1984) or control from the value of C stock in investigation year (2014). Amount of C sequestration has been estimated comparing with the present level of TOC in control at 15-30 and 30-60 cm soil layers due to not available of initial data for sub-surface soil.

$\Delta TOC = TOC_i - TOC_{presoil/control}$ …………(2)

Where, TOC_i is TOC stock in year i and $TOC_{pre\ soil/control}$ is TOC stock in 1984 or control plot

C sequestration rate was calculated according to the following equation.

$$Rseq = \frac{TOC_i - TOC\ pre\ soil}{T}$$

Where, TOC_i is Final SOC (Mg ha^{-1}), $TOC_{pre\ soil}$ is Initial SOC (Mg ha^{-1}), Rseq is C sequestration rate (Mg $ha^{-1} ha^{-1} Yr^{-1}$) and T is Time (years)

Data analysis: The data were processed using STPR software.

RESULTS AND DISCUSSION

Change in TOC, bulk density and TOC stock: TOC in 1984 was 12.18 g kg^{-1} while after 30 years of varying nutrient application ranged from 11.00 to 15.64, 9.34 to 13.26 and 7.82 to 11.56 g kg^{-1} at 0-15, 15-30 and 30-60 cm depth, respectively. A higher TOC was stored in surface soil (0-15 cm) decreasing with depth in all treatments. Maximum accumulation of TOC was observed with super optimal NPK (180:80:40) + Zn + FYM which was at par to 100% NPK (120:40:40) + Zn + FYM, while control plot soil contained the lowest value at all the three depth (Table 2). The increment in TOC under the optimal and balanced application of inorganic fertilizer alone or with FYM is ascribed to greater input of root biomass because of better crop growth along with the

Table 1. Application rates for Nitrogen (N), Phosphorous (P), Potassium (K) and Farm Yard Manure (FYM) for different treatments from 1984 to 2014

Symbol	Treatment	Inorganic fertilizer (Kg ha^{-1})			FYM (t ha^{-1})	Symbol	Treatment	Inorganic fertilizer (Kg ha^{-1})			FYM (t ha^{-1})
		N	P	K				N	P	K	
T1	Control	0	0	0	0	T8	NPK + FYM	120	40	40	5
T2	N	120	0	0	0	T9	NPK + Zn (F) + FYM	120	40	40	5
T3	NP	120	40	0	0	T10	$N_{180}P_{80}K$ + Zn (F) + FYM	180	80	40	5
T4	PK	0	40	40	0	T11	$N_{150}P_{80}K$	150	80	40	0
T5	NK	120	0	40	0	T12	$N_{180}P_{80}K$ + Zn (F)	180	80	40	0
T6	NPK	120	40	40	0	T13	$N_{180}P_{80}$ + Zn (F)	180	80	0	0
T7	NPK + Zn (F)	120	40	40	0	T14	NPK (DAP)	120	40	40	0

addition of FYM for 30 years. The TOC input over the 30 years due to an application of super optimal NPK(180:80:40) + Zn + FYM was 10393.60, 8780.8 and 8726.40 kg ha^{-1} in 0-15, 15-30 and 30-60 cm soil layer respectively. Rudrappa (2005) also reported the highest accumulation of TOC under 100% NPK + FYM while lowest in control in all the three-soil depth.

Fertilizer application with different doses alone or in conjunction with FYM did not influence the bulk density of soil significantly in 0-60 cm soil profile (Table 3). The decrease in bulk density over the years with fertilizer and manure application can be ascribed to the addition of root and plant biomass *vis-à-vis* conversion of some micro-pores into macro-pores due to cementing action of organic acids and polysaccharides formed during the decomposition of organic residues.

After 30 years, TOC stock in 0-60 cm soil profile greatly enhanced to 94.18 Mg C ha^{-1} due to application of 100 % NPK+ Zn + FYM and 106.30 Mg C ha^{-1}in super optimal NPK (180:80:40) + Zn + FYM treatment. In 1984 the initial value TOC stock in 0-15 cm soil layer was 24.30 Mg C ha^{-1}. The highest TOC stock in 0-15 cm layer was 30.28 Mg C ha^{-1} due to 100 % NPK + Zn + FYM, followed by super optimal NPK (180:80:40) + Zn + FYM, while in 15-30 and 30-60 cm soil layers greatest (26.45 and 49.59 Mg C ha^{-1}) TOC stock registered under super optimal NPK(180:80:40) + Zn + FYM and lowest (23.27, 20.59 and 37.30 Mg C ha^{-1}) found in control in all three depths respectively (Table 2). These results are comparable with other workers (Pathak et al 2011, Kumara et al 2014) where TOC stock was higher in treatments which were receiving integrated use of organic and inorganic fertilizers against sole use of chemical fertilizers and control. The development in TOC stock with nutrient management was due to the increased level of organic carbon in the soil. This must be because of direct application of FYM and addition of root biomass, root exudates and crop residues by rice and wheat over a period of 30 years. Similar results were observed by Benbi et al (2012) and Srinivasarao et al (2012).

Amount of C sequestered and C sequestration rate: In 0-15 cm soil layer after 30th crop of rice, all the treatments comprising fertilizers at varying levels with or without FYM increased the amount of C sequestered over the initial TOC stock (24.30 Mg C ha^{-1} in 1984) by 1.40 to 5.98 Mg C ha^{-1}. However, in control, it decreased by 1.03 Mg C ha^{-1}. The highest amount of C sequestered (5.98 Mg C ha^{-1}) was due to application of 100 % NPK + Zn + FYM, which was at par to super optimal NPK(180:80:40) + Zn + FYM and lowest in 100 % N with only 1.40 Mg C ha^{-1} (Table 2). In 15-30 cm and 30-60 cm soil layer, amount of C sequestered showed a significant effect of different fertilizer treatments either alone or in combination with FYM over 100 % N. Amount of C sequestered ranged from 2.14 to 5.86 Mg C $ha^{-1}$and 1.10 to 12.29 Mg C ha^{-1} in 100 % N and super optimal NPK

Table 2. Total soil organic carbon (TOC) and C sequestration in the different horizon of rice soils under long-term fertilization

Treatment	TOC (g kg^{-1})			TOC stock (Mg C ha^{-1})			Amount of C sequestered (Mg C ha^{-1})			C sequestration rate (Mg C ha^{-1} yr^{-1})		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
Pre-Soil	12.18	-	-	24.30	-	-	-	-	-	-	-	-
T1	11.00	9.34	7.82	23.27	20.59	37.3	-1.03	-	-	-0.03	-	-
T2	12.24	10.31	8.05	25.7	22.73	38.4	1.40	2.14	1.1	0.05	0.07	0.04
T3	13.15	10.88	8.50	27.22	23.66	40.04	2.92	3.07	2.74	0.10	0.1	0.09
T4	12.92	10.65	8.39	26.94	23.32	39.52	2.64	2.73	2.22	0.09	0.09	0.07
T5	12.58	10.54	8.16	26.42	23.08	38.68	2.12	2.49	1.38	0.07	0.08	0.05
T6	13.94	11.56	8.76	28.65	24.8	40.73	4.35	4.21	3.43	0.15	0.14	0.11
T7	14.28	12.24	9.52	29.2	25.89	43.7	4.90	5.3	6.4	0.16	0.18	0.21
T8	14.96	12.81	10.54	29.4	26.13	45.85	5.10	5.54	8.55	0.17	0.18	0.29
T9	15.53	12.92	10.88	30.28	26.16	47.33	5.98	5.57	10.03	0.20	0.19	0.34
T10	15.64	13.26	11.56	30.26	26.45	49.59	5.96	5.86	12.29	0.20	0.20	0.41
T11	14.35	12.47	9.86	28.84	26.19	44.67	4.54	5.6	7.37	0.15	0.19	0.25
T12	13.96	11.90	9.18	28.48	25.53	42.47	4.18	4.94	5.17	0.14	0.16	0.17
T13	14.42	12.58	10.09	28.77	26.23	45.41	4.47	5.64	8.11	0.15	0.19	0.27
T14	13.26	11.22	8.73	27.45	24.4	40.86	3.14	3.81	3.56	0.11	0.13	0.19
CD (p=0.05)	1.37	1.22	1.17	NS	NS	NS	0.18	0.33	0.44	0.01	0.01	0.02

(180:80:40)+ Zn + FYM through 15-30 cm and 30-60 cm soil layer, respectively. This enhanced level of C sequestration with the addition of FYM + inorganic fertilizers might be due to better crop growth with higher roots biomass production, higher return of left over surface residues and slower breakdown or constant mineralization of added organic residues resulting in more SOC accumulation (Mandal et al 2007). Higher C sequestration in a 33-year-old rice-wheat system due to application of FYM and the cropping system has greater capacity to sequester C because of high C input through enhanced productivity (Kukal et al 2009).

After 30 years, with regard to initial status of carbon i.e., 1984, the rate of C sequestration in 0-15 cm soil layer showed a statistically significant differences among various treatments and it ranged from 0.05 to 0.20 Mg C $ha^{-1} yr^{-1}$. In contrast a negative rate (-0.03 Mg C $ha^{-1}yr^{-1}$) was observed in control wherein no extraneous nutrients were provided. The highest C sequestration rate was observed due to application of 100 % NPK+ Zn + FYM and super optimal NPK(180:80:40) + Zn + FYM much lower with 100 % N. The rate of C sequestration varied from 0.07 to 0.20 Mg C $ha^{-1}yr^{-1}$ and 0.04 to 0.41 Mg C $ha^{-1}yr^{-1}$ in 15-30 cm and 30-60 cm soil layer with the application of various fertilizer with or without FYM (Table 2). The increase in C sequestration rate with the addition of FYM and inorganic fertilizers might be due to better crop growth, higher root biomass and higher return of left over surface plant residues in soil. Pathak et al. (2011) observed rate of C sequestration in the NPK + FYM treatment was 0.33 Mg C ha^{-1} yr^{-1} whereas in the NPK treatment was 0.16 Mg C ha^{-1} yr^{-1}.

Soil enzymes and yield trends: The hydrolysis of FDA was increased significantly under various fertilizer combinations with or without FYM in all the soil layers of profile up to 60 cm (Table 3). In 0-15 cm layer hydrolysis of FDA ranged from 110.28 to 290.73 µg fluorescein h^{-1} g^{-1} dry soil, highest being produced due to super optimal NPK(180:80:40)+ Zn + FYM which was at par with 100 % NPK + Zn + FYM and 100 % NPK + FYM and lowest in control. In 15-30 and 30-60 cm soil layer, the greatest value of hydrolysis of FDA to the tune 250.70 and 105.71 µg fluorescein h^{-1} g^{-1} was measured with super optimal NPK(180:80:40)+ Zn + FYM followed 100 % NPK + Zn + FYM and lowest (60.15 and 15.03 µg fluorescein h^{-1} g^{-1}) in control. The FDA enhanced under balanced application of inorganic fertilizer alone or in conjunction with FYM, which might be due to the higher levels of organic matter, coupled with the presence of metabolically active micro-organisms (Taylor et al 2002). The adherence of enzymes to the colloids of the FYM also increase the rate of fluorescein diacetate hydrolysis under FYM treated plots (Nannipieri et al 2003).

After 30th cycle of rice, in surface and sub-surface soil layers (0-15 cm, 15-30 cm) the *β*-glucosidase activity increased significantly in all treatments over control (Table 3). Highest *β*-glucosidase activity of 231.07 µg PNP g^{-1} soil h^{-1} in 0-15 cm layer was assessed in soil from super optimal NPK (180:80:40)+ Zn + FYM, which was at par with 100 % NPK +

Table 3. Bulk density and enzymatic activities in the different horizon of rice soils under long term fertilization

Treatment	B.D. (Mg m^{-3})			Fluorescein diacetate activity (µg fluorescein $g^{-1}h^{-1}$)			*β*-glucosidase activity (µg PNP g^{-1} h^{-1})			Grain yield (Kg ha^{-1})
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	
T1	1.41	1.47	1.59	110.28	60.15	15.03	50.32	44.73	12.80	2118
T2	1.40	1.47	1.59	149.88	68.13	25.08	64.29	61.50	13.73	3024
T3	1.38	1.45	1.57	173.33	90.23	44.13	87.59	68.02	19.32	5102
T4	1.39	1.46	1.57	170.43	80.20	35.10	80.48	65.22	15.59	3080
T5	1.40	1.46	1.58	150.38	70.18	28.33	78.61	62.50	14.66	2917
T6	1.37	1.43	1.55	190.48	110.28	55.15	101.57	88.52	23.04	5399
T7	1.35	1.41	1.53	209.51	130.33	65.18	104.50	99.84	27.70	5696
T8	1.31	1.36	1.45	270.68	210.45	99.23	215.25	120.20	33.30	6809
T9	1.30	1.35	1.45	280.70	219.50	101.25	228.29	149.01	37.02	6825
T10	1.29	1.33	1.43	290.73	250.70	105.71	231.07	191.95	44.48	6781
T11	1.34	1.40	1.51	210.53	160.40	70.81	108.08	90.88	28.64	6094
T12	1.36	1.43	1.54	205.50	125.30	57.71	102.50	97.84	25.84	5714
T13	1.33	1.39	1.50	240.60	170.43	75.20	137.91	117.41	30.50	6292
T14	1.38	1.45	1.56	180.45	100.25	45.13	100.63	81.07	21.18	5472
CD (p=0.05)	NS	NS	NS	20.78	15.18	6.85	13.02	11.02	4.39	403

Zn + FYM. In 15-30 and 30-60 cm soil layer the highest *β*-glucosidase activity of 191.95 and 44.48 μg PNP g^{-1} soil h^{-1} under super optimal NPK (180:80:40) + Zn + FYM, while lowest (44.73 and 12.80 μg PNP g^{-1} soil h^{-1}) in control. The glucosidase enzyme activity increases with the use of FYM along with fertilizer, resulting in high availability of C in the soil and improves the microbial population. Similar results were reported by Zhang et al. (2010). Srinivas et al (2015) also observed highest activity of β-glucosidase due to combined application of FYM and mineral fertilizers. Similarly, higher β-glucosidase activity in organic amended soils as compared to that of the soils with mineral fertilization and control has been reported (Gopinath et al 2007).

Grain yield of rice varied from 2118 to 6825 kg ha^{-1} with the application of various fertilizer with or without FYM, respectively and effects produced due to different combinations of fertilizer application were statistically significant in all treatments over control. Maximum grain yield (6825 kg ha^{-1}) was with 100 % NPK +Zn + FYM which was at par with 100 % NPK + FYM and super optimal NPK (180:80:40) + Zn + FYM and minimum in control (Table 3). The increase in grain yield due to addition of organics through FYM may be attributed to supply of N, P, K and micronutrients in addition to the recommended dose of fertilizers and increase in total N, P and K uptake. An application of FYM also acts a source of substrate for microbial metabolism resulting in enhanced microbial activity and subsequently nutrient transformations resulting in enhanced plant growth and yield. Thind *et al*. (2016) reported increase in N, P and K uptake to the tune of 29 to 32 %, 29 to 33 % and 27 to 49% in wheat due to FYM which increased grain and straw yield. The integrated supply of nutrients found beneficial in recording higher grain and straw yield of rice and wheat. The results are in close conformity with the findings of others (Saini et al 2005, Kundu et al 2008).

CONCLUSIONS

The continuous application of balanced inorganic fertilizer alone and with FYM for 30 years significantly improved TOC, C sequestration, fluorescein diacetate (FDA) activity, *β*-glucosidase activity and grain yield compared to control and imbalanced fertilizer application under rice-wheat sequence in sub-humid and sub-tropic of India. This study concludes that application of super optimal NPK (180:80:40) + Zn + FYM and 100 % NPK + Zn + FYM was most promising and efficient nutrient management practices for improving TOC stock, C sequestration, associated enzymatic activities and crop yield. This practice should be recommended to farmers for improving soil health, reducing cost of production and improving agricultural economy.

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Evaluation of Integrated Application of Organic and Inorganic Nutrient Sources on Growth and Nutrient Uptake by Cucumber (*Cucumis sativus* L.)

Saurabh Sharma, Jagjeet Chand Sharma, Yog Raj Shukla, Manisha Negi and Kapil Sharma

Department of Soil Science and Water Management
Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, India
E-mail: lakhanpal9596@gmail.com

***Abstract*:** The present study was carried out on cucumber cv. K-75 during *kharif* , 2018 and 2019. The experiment comprised of nine treatments of different nutrient sources including organic manures and inorganic fertilizers. The effects of organic manures (farmyard manure, vermicompost and jeevamrut) alone and in conjugation with inorganic fertilizers on growth, nutrient uptake of cucumber were observed. Integrated use of inorganic fertilizers and organic manure significantly influenced plant growth, yield and nutrient uptake by crop. The highest leaf area (394.3 cm^2), vine length (3.1 m), fruit weight (273.5 g) and NPK uptake (143.6, 31.2 and 153.4 kg ha^{-1}, respectively) was in. RDF + FYM @ 100 q ha^{-1}. Increment in NPK uptake under FYM @ 100 q ha^{-1} + Jeevamrut @ 5% was 52.7, 53.2 and 46.7% over control. The current study conclude that the better understanding of importance of integrated nutrient management could be a sustainable module in maintaining soil fertility thus enhancing nutrient uptake and enhanced soil health as evident by soil fertility status of soil after crop harvest.

***Keywords*:** Cucumber, Nutrient sources, FYM, Vermicompost, Jeevamrut, Nutrient uptake

In the world production of cucumber in 2019 was around 87.8 million tonnes and in India was 1.9 lakh tonnes that makes this crop of utmost importance (FAO 2021). Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem, soil health, including biodiversity, biological cycles and soil biological activity. This is achieved by using agronomic, biological and mechanical methods, as opposed to use of synthetic materials to fulfill any specific function within the system (Bokhtiar et al 2008). The organic agriculture is a system that relies on ecosystem management rather than external agricultural inputs (Samman et al 2008). Nurturing effect of native farm produced products like Farm Yard Manure (FYM), Vermicompost (VC) and Jeevamrut supplement soil fertility by enhanced mineralization rate of soil nutrients and meager reports are available on soil microbial quality proving their potential (Amalraj et al 2013). FYM production is easily accessible with straw, cow dung and cow urine and apart from supplying nutrients it supplements the soil with improved physical conditions reveals good potential for its use (Ram et al 2016, Ali et al 2019). Vermicompost application stimulates soil microbial activity and their growth helps in mineralization of plant nutrients, soil aeration, water holding capacity and availability of plant nutrients eventually improves soil fertility (Gill et al 2019). Liquid manures like jeevamrut enhanced microbial activity in soil and ultimately ensure the availability and uptake of nutrients and producing plant growth promoting substances (Palekar 2006, Gore and Sreenivasan 2011, Ukale et al 2016). Integrated nutrient management (INM) refers to use of both the sources *i.e.*, organic and inorganic, for balancing fertility of soil and providing appropriate nutrient level to plants (Negi et al 2021) and helps to restore and sustain soil fertility and crop productivity also helps to check the emerging deficiency of nutrient other than N, P and K (Sachan et al 2017). The main aim of INM is to minimize the use of chemical fertilizers without immolating the yield (Singh et al 2020). Farmers have experienced significant financial losses as a result of the widespread nutrient deficiency that has developed in soil as a result of intense cropping and deterioration of soil health due to excessive use of synthetic fertilizers (Negi et al 2022a). The conjunctive use of different organic sources improve soil health and helps in maximizing production as it involves utilization of local sources and hence, turned to be rational, realistic and economically viable way of supplying nutrients to crop (Singh and Pandey 2010). The purpose of this investigation were to investigate the impact of different nutrient sources on crop growth find out the changes in nutrient uptake by cucumber under the influence of different manures and fertilizers.

MATERIAL AND METHODS

Study area: The experiment was conducted at Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP). It is located at 30° 52´ N latitude and 77° 11´ E longitude and at an elevation of 1175 m above mean sea level with an average slope of 7-8 per cent for two consecutive years *i.e.* 2018–19 and 2019–20. Experiment was laid out in a randomized block design with three replications comprising nine treatments (Table 1).

Recommended dose of fertilizers for cucumber is N 100, P 50 and K 60 kg ha^{-1}. Nitrogen, Phosphorus and Potassium were used as inorganic fertilizers in the form of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. In the inorganic plots, whole quantity of FYM, SSP and MOP fertilizers were applied at the time of field preparation, whereas, urea was applied in three split doses with half as basal dose and remaining quantity of N was applied in two equal splits at monthly interval after transplanting. The whole quantity of FYM (0.54% N, 0.33% P and 0.54% K) and VC (1.38% N, 0.46% P and 0.63% K) was given before transplanting as per the treatment of the experiment in the organic plots. The Jeevamrut (1.41% N, 0.92% P and 0.05% K) was prepared from 10 kg cow dung plus 10 L cow urine added to 100 L of water, mixed and kept for about one week. It was applied to the soil at fortnightly interval along with the irrigation water @ 5% per plot, per application after establishment of the seedling. Five plants were randomly selected and tagged in each treatment to study the plant growth, yield characteristics and nutrient uptake. Leaves, vines and root samples were collected at the time of harvest for chemical analysis. All the samples were washed with distilled water, dried in shade and then the samples were cut into pieces and oven dried at 60°C. Well ground samples of known weight of bulbs and leaves were digested in di-acid mixture prepared by mixing concentrated HNO_3 and $HClO_4$ in the ratio of 4:1 observing all relevant precautions as laid down by Piper (1966) for estimating P and K. Separate digestion was carried out for N estimation using concentrated H_2SO_4 and digestion mixture as suggested by Jackson (1973). In leaves, vines and roots, N was estimated by Microkjeldahl method (Jackson 1973), P using Vando-molybdate phosphoric yellow colour method (Jackson 1973) and K by Flame Photometer method (Jackson 1973). The nutrient uptake by leaves, vines and root was calculated using the following formula:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter yield (kg/ha)}}{100}$$

The data for two seasons were pooled and subjected to analysis of variance by OPSTAT program and significance of result was verified.

RESULTS AND DISCUSSION

All the treatments of fertilizers and manures recorded significantly higher leaf area as compared to control during both the years of study (Table 2). The significantly higher leaf area (394.3 cm^2) was under RDF + FYM @ 100 q ha^{-1} *i.e.* T_2 which was followed by FYM @ 100 q ha^{-1} + RDF through FYM (on N equivalent basis) *i.e.* T_4. Uniform flow of assimilates to sink was high in T_4 due to the balanced supply and slow release of nutrients *via*. FYM and vermicompost which increased nutritional status of the soil resulting into increased plant growth favorably with the production of more carbohydrates might be the reason of higher leaf area. The results are in conformity with Singh and Walia (2015) and Sharma et al (2017). Vine length differs significantly in most of the treatments. The maximum vine length (3.1 cm) was in T_2 which was followed by T_6. Significantly higher fruit length was in T_2 (16.9 cm) followed by T_6. Amalgamation of organic manures and inorganic fertilizer in T_2 might have maintained the soil nutrient status by supplying the macro nutrients majorly from the inorganic sources and all other important plant micro nutrients *via* organic manure (Shah et al 2020). Fruit weight of cucumber was significantly highest in T_2(273.5

Table 1. Treatment details

Treatment codes	Treatment details
T_1	Control (No application of manures and fertilizers)
T_2	RDF + FYM @ 100 q ha^{-1}
T_3	Jeevamrut @ 5%
T_4	FYM @ 100 q ha^{-1} + RDF through FYM (on N equivalent basis)
T_5	FYM @ 100 q ha^{-1} + Jeevamrut @ 5%
T_6	VC (on N equivalent basis of FYM) + RDF through FYM (on N equivalent basis)
T_7	VC (on N equivalent basis of FYM) + Jeevamrut @ 5%
T_8	FYM @ 100 q ha^{-1} (50%) + VC (on N equivalent basis of 50% FYM) + RDF through FYM (on N equivalent basis)
T_9	FYM @ 100 q ha^{-1} (50%) + VC (on N equivalent basis of 50% FYM) + Jeevamrut @ 5%

g) which was statistically at par with T_6 and T_8. The increase in fruit weight might be due to the incorporation of FYM in integrated nutrient module would have improved the supply of N to plant leading to better vegetative growth and fruit weight. Moreover, microorganisms present in FYM might have efficiently dissolved nutrients making them available to plants which would have promoted the nutrient uptake and increase in fruit weight (Pandey and Chandra 2013). Pooled analysis of data revealed that all the treatments of fertilizers and manures had significant effect on fruit diameter and significantly highest fruit diameter was observed in T_2. Among the pure organic treatments, highest fruit diameter was in T_8. Microorganisms present in organic manures along with inorganic fertilizers would have assisted the root growth and enhanced nutrient absorption might have boosted the production of hormones amplifying the production of carbohydrates and their accumulation in fruits *i.e.* increasing fruit diameter. These results were in line with the findings of Laxminarayana and Patiram (2006) in rice and Negi et al (2021) in onion.

All the integrated treatments with the organic and inorganic amendments influenced the uptake of nutrients and highest N uptake (122.5 kg ha^{-1}) by cucumber crop (leaves, fruits, vines and roots) was in RDF + FYM @ 100 q ha^{-1} *i.e.* T_2 (Table 3) which produced significant difference among all other treatments. It was followed by VC (on N equivalent basis of FYM) + RDF through FYM (on N equivalent basis). The percentage increase in N uptake by cucumber under RDF + FYM @ 100 q ha^{-1} was 3.3 per cent over VC. This increase in RDF + FYM @ 100 q ha^{-1} can be attributed to the conjoint use of inorganic manures accompanied with organic manures resulting in solubilization of nutrients and reduced leaching leading to accumulation of different nutrients in plants.

The highest P uptake (31.2 kg ha^{-1}) was observed in RDF + FYM @ 100 q ha^{-1} as compared to VC (on N equivalent basis of FYM) + RDF through FYM (on N equivalent basis) resulted in 10.57 per cent higher P uptake (Table 3). This surge in P uptake may be the result of remodeling FYM with NPK, increasing the P in soil solution through mineralization of organic P compounds due to solubilizing action of organic acids produced by prolonged decomposition of FYM. Pandey et al (2009) also reported same trend in wheat. The significantly higher K uptake (153.4 kg ha^{-1}) was in RDF + FYM @ 100 q ha^{-1} *i.e* T_2 which was significantly at par with VC (on N equivalent basis of FYM) + RDF through FYM (on N equivalent basis). The higher K uptake might be due to the release of K from K bearing minerals during decomposition of organic amendments *i.e.* vermicompost and FYM. Similar results were observed by Mitra et al (2010) in jute, Diksha and Rajpaul (2020) in wheat and Negi et al (2022b) in onion.

Table 3. Effect of different nutrient sources on NPK uptake by cucumber (Pooled for 2 years)

Treatment code	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	67.9	14.6	81.7
T_2	143.6	31.2	153.4
T_3	80.0	16.3	94.4
T_4	120.7	25.1	132.2
T_5	104.7	20.0	113.3
T_6	138.8	27.9	147.6
T_7	99.9	18.9	111.8
T_8	128.6	25.5	138.2
T_9	96.9	21.5	113.5
CD (P=0.05)	7.5	1.4	6.7
Y × T	10.6	1.9	9.4

Table 2. Effect of different nutrient sources on growth parameters of cucumber (Pooled for 2 years)

Treatment code	Leaf area (cm^2)	Vine length (m)	Fruit length (cm)	Fruit weight (g)	Fruit diameter (cm)
T_1	329.3	2.1	14.7	246.7	4.48
T_2	394.3	3.1	16.9	273.5	4.94
T_3	327.8	2.4	15.6	255.2	4.56
T_4	387.4	2.9	16.7	269.6	4.84
T_5	342.0	2.6	16.1	267.6	4.75
T_6	369.7	3.0	16.8	272.0	4.86
T_7	365.6	2.7	16.4	257.6	4.78
T_8	368.4	2.9	16.6	271.1	4.85
T_9	336.6	2.8	16.3	269.0	4.68
CD (p=0.05)	6.5	0.1	0.4	3.1	0.2
Y × T	NS	NS	NS	NS	NS

CONCLUSION

The application of RDF (N 100, P 50 and K 60 kg ha^{-1}) + FYM @ 100 q ha^{-1} significantly enhanced the growth and nutrient uptake by cucumber. Nutrient supplied through pure organic sources was not as effective as from inorganic fertilizers + FYM. Therefore, combined use of inorganic fertilizers and organic manures can be suggested for sustainable production of cucumber.

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Dynamics of Soil Potassium Under Prominent Cropping Systems of Nellore District, Andhra Pradesh, India

G.R. Charankumar and V. Munaswamy

Department of Soil Science and Agricultural Chemistry
S.V. Agricultural College, Tiruapti-517 502, India
E-mail: charangrkumar@gmail.com

Abstract: In the present investigation five prominent cropping systems of Nellore district of Andhra Pradesh *viz.*, paddy-paddy, fallow-blackgram, fallow-bengalgram, fallow-paddy and groundnut-paddy were selected to study dynamics of soil potassium. The highest mean available K was recorded under groundnut-paddy cropping sequence (249.36 mg kg^{-1}) in surface soils, while in sub-surface soils under fallow-blackgram cropping sequence (164.48 mg kg^{-1}). Highest mean water-soluble K was found under paddy-paddy cropping sequence both in surface (33.67 mg kg^{-1}) and sub-surface soils (23.87 mg kg^{-1}). Highest mean exchangeable K was recorded under groundnut-paddy cropping sequence (230.20 mg kg) in surface soils, while in sub-surface soils under fallow-blackgram cropping sequence (152.96 mg kg^{-1}). Highest mean non-exchangeable K was found under groundnut-paddy cropping sequence at both surface (642.70 mg kg^{-1}) and sub-surface soils (668.54 mg kg^{-1}). Highest mean lattice K and total K were observed under paddy-paddy cropping sequence at both surface (30044.48 and 30572 mg kg^{-1}, respectively) and sub-surface soils (18671.76 and 19158 mg kg, respectively). The forms of potassium were positively correlated among themselves indicating dynamic equilibrium among different forms K in soils under prominent cropping systems of Nellore district.

Potassium (K) is third most important plant nutrient after nitrogen and phosphorus which plays vital roles in osmoregulation, cation-anion balance, water balance and transport of assimilates in plants (Epstein and Bloom 2005). It also acknowledged as master cation because it occurs in the highest concentration in the plant cell sap. The preference of farmers in our country for nitrogen, phosphorus over potassium is reflected in the skewed N: P_2O_5: K_2O consumption ratio, which was 6.6:2.6:1 in 2018-19 over the golden ratio of 4:2:1 (FAI 2019). Phytoavailability K in various forms influenced by the equilibrium and kinetic reaction between forms of soil-K, moisture content, temperature and bivalent cations concentration in solution and on the exchanger phase. Potassium in soil exists in four forms, namely water soluble K, exchangeable K, non-exchangeable K and lattice K, which are in dynamic equilibrium that controls its phytoavailability. Bioavailable pool of K comprises of water soluble K and the exchangeable K held on negatively charged exchange surfaces in the soil. The major portion of the reserve of available K in soil is contributed by non-exchangeable K and a primary factor in determining soil K fertility (Wang et al 2016). The potassium fractions exist in dynamic equilibrium among them which govern the K nutrition in crops and are important for the growth of higher plants and microbes. Impaired nutrient consumption largely affects the status and forms of potassium distribution thereby deteriorating soil fertility and decline in crop productivity. Imbalanced K fertilization for long periods of time may adversely affect the K release rates in a soil, ultimately lowering its K supplying capacity to plants. Such low K application affects the soil's K-fertility status over long period (Das et al 2018, 2019). The proficiency on various forms potassium helps to understand conditions admiring of potassium availability to growing crops in the soil and also for potassium management in order to determine the long-term sustainability of cropping systems. Therefore, there is a need to assess potassium fractions in the soil is imperative to optimize crop productivity and cropping systems through sound fertilizer recommendations. Present study was undertaken to study the distribution of potassium forms under different cropping sequences in Nellore district of Andhra Pradesh.

MATERIAL AND METHODS

An investigation was carried out in S. V. Agricultural College, Tirupati, during 2019 to assess the fractions of soil potassium from prominent cropping systems of Sri Potti Sri Ramalu (S.P.S.R) Nellore district of Andhra Pradesh. The district is situated at Geographical Co-ordination of 14° 26' 33.3564'' N and 79° 59' 11.2488'' E. Nellore is located at 18m above mean sea level. Nellore's climate is classified as tropical. The average temperature is 28.3°C. Mean annual precipitation 33.7 inch per year. Five soil samples from each cropping system at 0-15cm and 15-30cm depths were collected from farmers' fields' *viz.,* paddy-paddy, fallow-blackgram, fallow-bengalgram, fallow-paddy and groundnut-paddy cropping sequences during 2018-19. These are prominent cropping sequences which were followed by the Nellore farmers since 10-12 years continuously on the same fields. Soil sample were air-dried, ground in a wooden pestle with mortar and passed through a 2-mm stainless steel sieve and used for determining various soil properties by following standard procedures (Table 1). Simple correlation coefficients ('r') were also worked out for relationships among potassium forms using Statistical Package for Social Sciences (SPSS) software.

RESULTS AND DISCUSSION

Soil properties: The pH indicated that all the soils were alkaline in reaction. The soils from all cropping sequences were calcareous in nature and non-saline. The soil texture ranged from sandy clay loam to clay (Table 2).

Available K (Avl-K): The mean available K content of surface soils varied from 63.4 mg kg^{-1} in fallow-paddy cropping system to 249 mg kg^{-1} in groundnut- paddy cropping sequence, respectively and contribution of available K to total K ranged from 0.260 to 1.34 per cent. In sub-surface soils average available K content varied from 43.3 mg kg^{-1} in fallow-paddy cropping system to 164 mg kg^{-1} in fallow-blackgram cropping sequence (Table 3). The contribution of available K to total K ranged from 0.350 to 2.53 per cent. The highest available potassium was in soils of groundnut-paddy cropping system in surface soils might be due to application of potassic fertilizers to surface layers only and in sub-surface soils available potassium was higher in fallow-blackgram cropping system, which might be due to its removal by crops from the surface soil and leaching and accumulation in the subsurface soil containing higher amount of clay and organic matter (Kundu et al 2014) and lowest available potassium was in fallow-paddy cropping system in both surface and sub-surface soils, which might be due to higher uptake of K resulted in depletion of K (Elbaalawy et al 2016). The highest available potassium was observed in surface soils than in sub-surface soils in all cropping systems, which might be attributed to more intense weathering, release of K from organic residues, application of K fertilizers and upward translocation of potassium from lower depth along with capillary raise of ground water (Rao et al 2017).

Water soluble K (WS-K): The mean water-soluble K content

Table 1. Analytical methods followed during chemical analysis

Properties	Methodology	Reference
Available Potassium	Neutral *1N* NH_4OAC extraction	Jackson (1973)
Forms of Potassium	Flame photometry	
Water Soluble K	1:5 Soil water suspension	Jackson (1973)
Exchangeable K	Available K – Water soluble K	
Non-exchangeable K	Boiling *1N* Nitric acid extraction	Wood and De Turk (1941)
Lattice K	Total K – (Available K + Non-exchangeable K)	Wiklander (1954)
Total K	HF – $HClO_4$ extraction	Pratt (1965)

Table 2. Physico-chemical properties of soils under cropping systems of Nellore district

Cropping systems	Textural class	pH		EC (dSm^{-1})		CEC [c mol p(+) kg^{-1}]
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm
Paddy – Paddy	Sandy clay loam	7.42 (7.31-7.60)	7.23 (7.09-7.52)	0.028 (0.013-0.039)	0.026 (0.013-0037)	6.39 (6.0-6.73)
Fallow-Blackgram	Clay loam	8.18 (8.08-8.31)	8.24 (8.13-8.31)	0.012 (0.01-0.014)	0.015 (0.012-0.019)	13.60 (13.10-14.62)
Fallow – Bengalgram	Clay	7.93 (7.82-8.11)	7.73 (7.12-7.97)	0.029 (0.023-0.037)	0.025 (0.013-0.038)	33.06 (31.31-36.34)
Fallow-Paddy	Sandy clay loam	7.54 (7.40-7.74)	8.36 (8.23-8.55)	0.092 (0.077-0.110)	0.033 (0.022-0.055)	21.77 (20.72-22.11)
Groundnut - Paddy	Sandy clay loam	7.69 (7.54-7.84)	7.74 (7.55-7.87)	0.028 (0.016-0.038)	0.032 (0.026-0.049)	10.70 (9.88-11.44)

Figures in parentheses represents range

of surface soils varied from 6.23 mg kg^{-1} in fallow-paddy cropping system to 33.67 mg kg^{-1} in paddy-paddy cropping. The water soluble K contributed least to total K and ranged from 0.030 to 0.130. In sub-surface soils water soluble K content varied from 5.61 mg kg^{-1} in fallow-paddy cropping system to 23.8 mg kg^{-1} in paddy-paddy cropping sequence (Table 3). Contribution of water soluble K to total K ranged from 0.070 to 0.220 per cent. The highest water soluble K was observed in soils of paddy-paddy cropping system in both surface and sub-surface soils, which might be due to high dose of K fertilizers were applied to paddy in both seasons while lowest water soluble K was observed in fallow-paddy cropping system at both depths, which might be due to which might be due to non application of K fertilizers to first crop. The highest water soluble K was observed in surface soils than in sub-surface soils in all cropping systems, which might be attributed to accumulation of potassium applied through fertilizers in the surface layers. Similar results were reported under rice - wheat cropping system by Jassal et al (2012) and Kumari and Nisha (2014).

Exchangeable K (EX-K): The exchangeable K content of surface soils varied from 57.19 mg kg^{-1} in fallow-paddy cropping system to 230 mg kg^{-1} in groundnut - paddy cropping sequence. The exchangeable K contribution to total K ranged from 0.240 to 2.02 per cent. In sub-surface soils exchangeable K content varied from 37.78 mg kg^{-1} in fallow-paddy cropping system to 152 mg kg^{-1} in fallow-blackgram cropping sequence (Table 3). This fraction contributed 0.230 to 2.31 per cent to total K. The highest exchangeable K was observed in soils of groundnut - paddy cropping system and fallow-blackgram cropping system in surface and sub-surface soils, respectively which might be due to application of fertilizers during cultivation of these crops and lowest exchangeable K was in fallow-paddy cropping system in both surface and sub-surface soils, which might be due to non application of potassic fertilizers to the first crop. The data further revealed that highest exchangeable K was observed in surface soils than in sub-surface soils in all cropping systems, which might be attributed to capillary action of K ions from lower layer to the upper layer and paved for the crop uptake (Divya et al 2016).

Non-exchangeable K (NEX-K): The non-exchangeable K content of surface soils varied from 231 mg kg^{-1} in groundnut-paddy cropping system to 588 mg kg^{-1} in fallow-blackgram cropping sequence with mean values of 265 and 551 mg kg^{-1}, respectively. This fraction contribution to total K ranged from 1.29 to 4.98 per cent. In sub-surface soils non-exchangeable K content varied from 359 mg kg^{-1} in fallow-paddy cropping system to 454 mg kg^{-1} in paddy - paddy cropping sequence with mean of 387 and 418 mg kg^{-1}, respectively (Table 3). Per

Table 3. Distribution of different forms of potassium under prominent cropping systems

Cropping Systems	Available K (mg kg^{-1})		Water soluble K (mg kg^{-1})		Exchangeable K (mg kg^{-1})		Non-exchangeable K (mg kg^{-1})		Lattice K (mg kg^{-1})		Total K (mg kg^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	0-15 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Paddy-Paddy	132.89 (109.55-145.70)	68.00 (61.05-77.35)	33.67 (26.75-38.35)	23.87 (17.95-28.15)	99.22 (82.80-107.35)	44.13 (40.60-49.20)	394.63 (364.60-433.70)	418.24 (390.45-454.65)	30044.48 (25743.80-33370.60)	18671.76 (15832.80-20383.50)	30572 (26230-33950)	19158 (16290-20910)
Fallow-Blackgram	238.20 (201.35-275.95)	164.48 (149.70-175.50)	14.34 (9.95-20.05)	11.52 (10.20-14.00)	223.86 (191.40-255.90)	152.96 (139.10-161.50)	551.44 (508.15-588.85)	397.12 (362.55-432.40)	10278.36 (9260.50-11254.30)	7340.40 (7031.00-7660.10)	11068 (9970-12090)	7902 (7600-8210)
Fallow-Bengalgram	145.18 (124.30-171.20)	128.71 (116.75-139.00)	7.61 (5.95-9.45)	6.35 (5.60-8.05)	137.57 (118.35-161.75)	122.36 (111.00-130.95)	532.24 (510.10-548.00)	407.55 (374.00-423.00)	14660.58 (13214.50-16480.80)	6263.74 (4645.40-7278.00)	15338 (13870-17200)	6800 (5150-7840)
Fallow-Paddy	63.42 (55.10-73.80)	43.39 (38.80-46.85)	6.23 (5.45-7.45)	5.61 (5.25-5.95)	57.19 (49.30-66.35)	37.78 (33.45-41.00)	349.24 (279.45-396.20)	387.25 (359.55-407.95)	23709.34 (20918.30-25050.00)	8133.36 (7479.50-8586.80)	24122 (21320-25520)	8564 (7930-9010)
Groundnut – Paddy	249.36 (204.55-78.85)	158.26 (145.45-173.35)	19.16 (14.95-22.80)	13.65 (13.10-15.10)	230.20 (189.60-256.05)	144.61 (132.35-159.80)	265.95 (231.45-281.55)	395.86 (361.30-446.85)	18146.69 (15314.50-19365.80)	5709.88 (4701.10-6662.80)	18662 (16280-20120)	6264 (5210-7210)

Figures in parentheses represents range

cent contribution of non-exchangeable K to total K varied between 2.18 and 5.99. The highest non-exchangeable K was in soils of fallow-blackgram cropping system and paddy-paddy cropping system in surface and sub-surface soils, respectively which might be due to presence of higher clay and organic matter content and lowest non-exchangeable K was observed in fallow-paddy cropping system at both depths, which might be due to crops are grown successively with less potassium application to soil as a result mining of K takes place (Sharma et al 2016). The highest non-exchangeable K was in sub-surface soils than in surface soils in all cropping systems, except in fallow-blackgram cropping system and fallow-bengalgram cropping system which might be attributed to release of potassium reserve pool to compensate the loss of available potassium by plant uptake and may be due to adsorption and fixation of K removed from surface through leaching. Similar findings were obtained by earlier researchers (Kundu et al 2014, Saini and Grewal 2014, Divya et al 2016).

Lattice K: The lattice K content of surface soils varied from 9260 mg kg^{-1} in fallow -blackgram cropping system to 33370 mg kg^{-1} in paddy-paddy cropping sequence with mean values of 10278 and 30044 mg kg^{-1}, respectively. Major portion of total K comprised of this fraction and contribution varied from 92.8 to 98.2 per cent. In sub-surface soils lattice K content varied from 4645 mg kg^{-1} in fallow-bengalgram cropping system to 20383 mg kg^{-1} in paddy-paddy cropping sequence with mean values of 6263.74 and 18671 mg kg^{-1}, respectively (Table 3). Per cent contribution of lattice K to total K ranged from 92.8 to 97.4. The highest lattice K was observed in soils of fallow-paddy and paddy-paddy cropping system in surface and sub-surface soils, respectively which might be due to type and nature of parent material present and degree of weathering however, lowest lattice K was in fallow-blackgram cropping system and fallow-blackgram cropping system in surface and sub-surface soils, respectively. The highest lattice K was observed in surface soils than in sub-surface soils in all cropping systems, which might be attributed to higher K-bearing minerals in their lattice structure (Anil et al 2009).

Total K: The total K content of surface soils varied from 9970 mg kg^{-1} in fallow - blackgram cropping system to 33950 mg kg^{-1} in paddy-paddy cropping sequence with mean values of 11068 and 30572 mg kg^{-1}, respectively. In sub-surface soils total K content varied from 5150 mg kg^{-1} in fallow-bengalgram cropping system to 20910 mg kg^{-1} in paddy-paddy cropping sequence with mean 6800 and 19158 mg kg^{-1}, respectively (Table 3). The highest total K was observed in soils of paddy-paddy cropping system in both surface and sub-surface soils, which might be due to high concentration of lattice K (Abdul et al 2013) and lowest was observed in fallow-blackgram cropping system and groundnut - paddy cropping system in surface and sub-surface soils, respectively. The highest total K was observed in surface soils than in sub-surface soils in all cropping systems which might be due to the presence of considerable amount of potassium bearing minerals as a reserve from external application to satisfy out the crop demand (Divya et al 2016).

Table 4. Correlation among different forms of potassium in surface soils under prominent cropping systems

	Avl-K	WS-K	EX-K	NEX-K	Lattice-K	Total-K
Avl-K	1					
WS-K	0.262	1				
EX-K	0.990**	0.123	1			
NEX-K	0.875**	-0.023	0.903**	1		
Lattice-K	-0.547**	0.574**	-0.646**	-0.642**	1	
Total-K	-0.531**	0.585**	-0.632**	-0.628**	0.999**	1

** Correlation is significant at the 0.01 level (2-tailed).* Correlation is significant at the 0.05 level (2-tailed)

Table 5. Correlation among different forms of potassium in sub-surface soils under prominent cropping systems

	Avl-K	WS-K	EX-K	NEX-K	Lattice-K	Total-K
Avl-K	1					
WS-K	0.304	1				
EX-K	0.982**	0.120	1			
NEX-K	0.433*	-0.090	0.469*	1		
Lattice-K	-0.539**	0.478*	-0.656**	-0.290	1	
Total-K	-0.526**	0.485*	-0.643**	-0.266	0.999**	1

** Correlation is significant at the 0.01 level (2-tailed).* Correlation is significant at the 0.05 level (2-tailed)

Correlation among forms of potassium under different cropping systems: The highest positive degree of significant correlation was between lattice K and total K followed by available K with exchangeable K, exchangeable K with non-exchangeable K, available K with non-exchangeable K, water soluble K with total K and lattice K at both surface (Table 4) and sub-surface soils (Table 5). Similar results were corroborated by earlier researchers (Dhakad et al 2017, Elbaalawy et al 2016, Kundu et al 2014 and Saini and Grewal 2014). All the forms of potassium at both depths were correlated with each other revealing the existence of dynamic equilibrium among them.

CONCLUSION

Soil K fractions in all cropping systems were found in the order of lattice K > non-exchangeable K > available K > exchangeable K > water soluble K. In S.P.S.R Nellore district, under rainfed conditions all the forms of potassium were highest in fallow-blackgram cropping system followed by fallow-bengalgram cropping system. Under irrigated conditions all the forms of potassium were highest in groundnut-paddy cropping system followed by paddy-paddy cropping system and fallow-paddy cropping system. At both soil layers different forms of K were positively and significantly correlated with each other in soils indicating dynamic equilibrium among different forms.

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Altering Microclimate of Broccoli Crop by Adjusting Transplanting Date, Mulching, and Irrigation Application in Mid Hill Zone of Himachal Pradesh

Pooran Mal Meena, R.K. Aggarwal and Purnima Mehta

Department of Environmental Science
Dr Y S Parmar University of Horticulture and Forestry Nauni, Solan-173 230, India
E-mail: rajeev1792@rediffmail.com

Abstract: Field experiments were conducted during the *rabi* seasons of 2021-22 to evaluate the microclimate of broccoli crops under three dates of transplanting, two mulching, and two irrigation levels at Nauni, Solan the mid-hill-sub humid agroclimatic region of Himachal Pradesh. Soil temperature was maximum during the transplanting stage in timely sown (28^{th} October) crop and decreased during the heading and harvested stage. Photosynthetically active radiation, relative humidity, soil moisture, and leaf area index from transplanting onwards was recorded higher in the timely sown crop and lower in the late sown crop while in the case of irrigation and mulching levels was higher under optimal irrigation and mulching application. At the heading stage, PAR interception was observed to be statistically highest (5.10) due to a higher leaf area index in the timely sown crop followed by the mid-sowing (4.19) and was lowest (3.03) in the late sown crop. Better crop growth and hence, leaf area index resulted in a higher PAR interception on timely sown with optimal irrigation and mulching level. Similarly, dry matter accumulation had a positive relation with chlorophyll content (R^2= 0.55). The higher the dry matter accumulation higher will be the chlorophyll content.

Keywords: Broccoli, Date of transplanting, Irrigation, Microclimate, Mulching and yield

Broccoli is native to the Mediterranean and East Asian regions. It is widely grown in China, India, the USA, Spain, Mexico, Italy, and other parts of the world. In India, it is generally grown in hilly areas of Nilgiri Hills, Himachal Pradesh, Uttar Pradesh, Jammu and Kashmir, and the Northern plains. In India, broccoli occupies nearly 4.5 lakh ha of the area with a production of 8.8 metric tons and productivity of 1.9 kg ha^{-1}. Broccoli grows best when exposed to an average daily temperature between 17-23°C. It requires about 12-16°C, 18-23°C, and 12-18°C temperature for seed germination, vegetative growth, and head development. Temperature below the optimum range delays maturity and led to small sprouts. Moreover, it cannot tolerate high temperatures as it produces poor-quality sprouts. Gouri et al (2005) reported that the growth of the crop largely depends upon the microclimate environment of the crop, which varies from the top of the canopy to the soil surface and affects the growth and yield of the crop. The broccoli plant growth and yield increase when dark mulch is used rather than light colour mulches which maintains the optimum soil temperature, hence dark mulch may be an option for broccoli production in areas with cool conditions. Singh et al (2021) showed that black mulch produced the highest yield of broccoli. The planting date plays an important role to enhance the yield and biomass of the crop. The extremely high temperature at the head development stage cause bolting and affects crop production. The late transplanting of the crop exposes high temperatures at the head development stage of the crop which influences the yield of the crop. Plants from delayed sowing failed to produce viable seeds under the agro-climatic condition of Assam (Gogoi et al 2016) as sowing timely produced the highest head yield. Broccoli planted on 1^{st} October produced a significantly higher diameter, as well as the perimeter of the flowering head compared to other planting dates (Obaid et al 2019). For irrigation scheduling and effective water management, an accurate estimation of evapotranspiration is required. However, factors that affect evapotranspiration are humidity, solar radiation, and crop growth stages. Evapotranspiration can be seen as an integrated response to all these factors and a major contributor to irrigation requirements. The commercial production of broccoli is an emerging challenge in the changing environmental conditions that makes it difficult for farmers to cultivate broccoli appropriately due to the lack of information to overcome these challenges. Therefore, the study was conducted by altering the microclimate of broccoli crop by adjusting transplanting dates, mulching and irrigation application in mid hill zone of Himachal Pradesh

MATERIAL AND METHODS

The field experiment was carried out at UHF, Nauni situated at 30.86 N latitude and 77.17 E longitude and an altitude of 1275 m above sea level. The crop nursery was sown on three different sowing dates 12th September, 2nd October and 23rd October. The crop was transplanted at three different transplanted dates (8th October, 28th October, and 18th November) with two mulching and irrigation levels during the *rabi* seasons of 2021-22. No fertilizers and pesticides were used in the present study. The UV-resistant black plastic mulch sheet 30-micron covered about 4.05 m^2 area was laid in the plots. The phenological stages of the crop were recorded by visual observations.

Evapotranspiration estimation (mm): Evapotranspiration was estimated using the formula given by the Papadakis method:

$$ET = 0.5262 \times (Emax - Emin - 2) \times \left(\frac{10}{30}\right)$$

Whereas, Emax, Emin-2: Saturation vapour pressure corresponding to average maximum temperature and average dew point temperature.

Tmax , Tmin: Maximum and minimum temperature

Soil temperature (^{o}C): Soil temperature was recorded at 15cm depth by using a soil thermometer. The soil temperature was recorded at different phenological stages.

Relative humidity under the canopy of the crop (%): Hygrometer was used to record relative humidity at different phenological stages. Morning and evening relative humidity was recorded under the canopy of the crop.

Soil moisture (%): Soil sample was collected in a moisture can and the wet weight of the sample was recorded. The soil sample was dried in a hot air oven at 105°C until a constant weight was obtained and the dry weight of the sample was recorded (Kelly 2004).

$$\text{Moisture content (on weight basis)} = \frac{\text{Fresh weight - Dry weight}}{\text{Dry weight}} \times 100$$

Leaf area index (LAI): The leaf area index was calculated by dividing the leaf area per plant by land area occupied by the plant. The leaf area index was calculated at the time of the different phenological stages.

$$LAI = \frac{\text{Leaf area}}{\text{Ground area}}$$

Dry matter accumulation: Each treatment received a portion of the complete plant from six selected plants per plot. Chopping was carried out after taking a new weight. The samples were dried in an oven at 60°C until they reached a consistent weight. The dry matter content of oven-dried samples was measured and expressed as a percentage.

$$\text{Dry matter content (\%)} = \frac{\text{Dried weight of sample}}{\text{Fresh weight of sample}} \times 100$$

Chlorophyll content: The chlorophyll content was estimated by using the method given by Hiscox and Israeistam, 1979. The fresh leaves were chopped to fine pieces under subdued light, 100 mg of chopped leaf samples were placed in vials containing 7 ml of Dimethyl sulphoxide, the vials were incubated at 65°C for half an hour, and the extract was then transferred to the graduated test tube and the final volume was made to 10 ml with Dimethyl sulphoxide. The optical density of the above extract was recorded on Spectrophotometer (Model: Spectronic-20) at 645 and 663 nm wavelength against Dimethyl sulphoxide blank.

The total chlorophyll content was calculated by using formula:

$$\text{Total chlorophyll} = \frac{20.2A645 + 8.02A663}{ax1000xw} \times V$$

Where; V = volume of extract made, a = length of light path in cell, w = weight of the sample taken A645 is absorbance at 645nm, A663 is absorbance at 663nm.

RESULTS AND DISCUSSION

Relative humidity: Significantly higher relative humidity (RH) was at the mid-sowing date (T_2) followed by the first sowing date (T_1) and lowest in the late sowing date (T_3) (Table 1). Among different phenophases, RH was highest at the vegetative stage (62%) followed by the heading, and was lowest at the harvesting stage. In the case of mulching levels, relative humidity was maximum in M_1 (61%) as compared to M_2 (54%) at the vegetative stage might be due to more vegetative growth. The relative humidity was higher under optimum irrigation I_1 (64%), due to higher soil moisture and lower soil temperature at the vegetative stage and hence, more availability of moisture under optimum irrigation level. Verma *et al.* (2018) also reported that soil moisture and relative humidity play important role in the growth and development of the crop.

Soil moisture: Significantly higher soil moisture was found in T_2 followed by T_1 and lowest in T_3 (Table 2). Among different phenophases, soil moisture was highest at the vegetative stage (63.6 %) followed by the heading and was lowest (52.5%) at the harvesting stage. In the mulching levels, soil moisture was maximum in M_1 (59.8 %) as compared to M_2 (52.50 %) at the vegetative stage might be due to more vegetative growth. Soil moisture was higher under optimum irrigation I_1 (63.2 %) at the vegetative stage.

Photosynthetically active radiation: At the transplanting and heading stage, PAR interception (%) was lower than vegetative as it increased with an increase in the leaf area index (Table 3). At the vegetative stage, PAR interception was observed to be statistically highest (522 Wm^{-2}) due to a higher leaf area index in T_2 followed by T_1 and was lowest

Table 1. Variation in relative humidity under different dates of transplanting, mulching and irrigation levels at different phenophases of crop

Treatment	Relative humidity (%)			
Date of transplanting	Transplanting	Vegetative	Heading	Harvesting
T_1	44	56	49	42
T_2	51	62	59	49
T_3	41	54	43	40
CD (p=0.05)	1.68	1.48	0.88	0.76
M_1 (Mulching)	49	61	53	44
M_2 (No Mulching)	42	54	48	43
CD (p=0.05)	1.37	1.21	0.72	0.62
I_1 (Irrigation)	53	64	54	41
I_2 (No Irrigation)	38	51	47	46
CD (p=0.05)	1.37	1.21	0.72	0.62

Table 2. Variation in soil moisture under different dates of transplanting, mulching and irrigation levels at different phenophases of crop

Treatment	Soil moisture (%)			
Date of transplanting	Transplanting	Vegetative	Heading	Harvesting
T_1	50.5	54.5	52.0	43.1
T_2	50.2	63.6	62.3	52.5
T_3	41.9	50.4	47.7	38.0
CD (p=0.05)	1.96	1.65	1.59	1.50
M_1 (Mulching)	52.7	59.8	57.9	48.0
M_2 (No Mulching)	42.4	52.5	50.0	41.0
CD (p=0.05)	1.60	1.35	1.30	1.22
I_1 (Irrigation)	53.4	63.2	61.6	52.0
I_2 (No Irrigation)	41.6	49.0	46.4	37.0
CD (p=0.05)	1.60	1.35	1.30	1.22

Table 3. Photosynthetically active radiation under different dates of transplanting, mulching and irrigation levels at different phenophases of crop

Treatment	Photosynthetically active radiation (Wm^{-2})				
Date of transplanting	Transplanting	Vegetative	Heading	Harvesting	Yield/plot (kg)
T_1	401	464	414	343	8.589
T_2	400	522	444	403	10.440
T_3	292	416	338	288	6.353
CD (p=0.05)	1.98	1.40	0.88	1.46	0.26
M_1 (Mulching)	369	468	402	348	9.714
M_2 (No Mulching)	359	466	397	341	7.207
CD (p=0.05)	1.62	1.15	0.72	1.19	0.21
I_1 (Irrigation)	370	469	402	352	9.166
I_2 (No Irrigation)	358	466	396	337	7.755
CD (p=0.05)	1.62	1.15	0.72	1.19	0.21

(416 Wm^{-2}) in T_3. Among mulching and irrigation levels, crop having mulching application (M_1) and optimal irrigation (I_1) captured more radiation, which might be due to better crop stand and hence higher leaf area index leading to a more PAR interception. At the vegetative stage, PAR interception was 468 Wm^{-2} under the mulching application. Similarly, the higher PAR interception was observed under I_1 (469Wm^{-2}) than under I_2 (466Wm^{-2}). Mehta and Dhaliwal (2022) also reported that normal sowing resulted in higher biomass production with a higher leaf area index, thus intercepting more of the available radiation within the canopy in different crops.

Leaf area index: The leaf area index was lower during the early stages of crop growth and increased with the growth of crop reaching a maximum at the vegetative and heading stage after sowing and after that, it started decreasing gradually as the crop reached senescence and maturity. At the transplanting stage, the leaf area index was observed to be lower than the vegetative and heading stages (Table 4). At the heading stage, PAR interception was statistically highest due to a higher leaf area index in T_2 (5.10) followed by T_1 (4) and was lowest (3.03) in T_3. Among mulching and irrigation levels, crop having mulching application (M_1) and optimal irrigation (I_1) captured more radiation, which might be due to better crop stand and hence higher leaf area index leading to a more PAR interception. At the vegetative stage, PAR interception was (4.41) under the mulching application. Similarly, the higher PAR interception was under I_1 (4.41) than under I_2 (3.80). Gupta et al (2017) also concluded that the leaf area gets reduced with delayed sowing which may be due to a decline in photosynthetic rate and poor leaf development leading to a lower leaf area index (LAI).

Evapotranspiration: Among different sowing dates, evapotranspiration at the harvesting stage was observed higher in T_3 followed by T_2 and lowest in T_3. The evapotranspiration was higher during the initial growth and harvesting period which decreased with the advancement of crop growth. At the harvesting stage due to an increase in soil temperature, the evapotranspiration in T_3 was 2.50 mm, whereas it was 2.10 mm in T_1 (Table 5). At the harvesting stage, the treatments with no mulching (2.37mm) and no irrigation (2.48mm) application recorded higher evapotranspiration. The higher soil temperature results in higher evapotranspiration and increases the water use availability to crop and affects the growth and yield of the crop.

Soil temperature: Soil temperature at the transplanted stage was observed higher in T_1 followed by T_2 and lowest in T_3. The soil temperature in T_1 was 29.2˚C, whereas in T_3 it was 17.7˚C at 1400 and 0730 hrs as respectively (Fig. 1). Higher soil temperature under earlier sowing might have proved beneficial for better crop establishment and growth. The soil temperature at the vegetative and harvesting stage was observed higher in T_3. At the harvesting stage, the treatments with mulching and no irrigation application recorded higher soil temperatures of 26.6 and 23.6˚C at 1400 and 0730 hrs respectively. The higher soil temperature results in higher evapotranspiration and increases the water use availability to crop and affects the growth and yield of the crop.

Regression relationship between dry matter accumulation and chlorophyll content at the heading stage of broccoli: The model explained 0.55 variations in dry matter accumulation with chlorophyll content under different transplanted dates, mulching and irrigation levels respectively (Fig. 2). The higher the dry matter accumulation and leaf area index increases the chlorophyll content of the crop under different treatments. Gupta et al (2017) also concluded that the leaf area gets reduced with delayed

Table 4. Leaf area index during different phenophase of broccoli

Treatment	Leaf area index			
Date of transplanting	Transplanting	Vegetative	Heading	Harvesting
T_1	0.06	3.44	4.19	0.81
T_2	0.04	4.21	5.10	1.08
T_3	0.05	2.70	3.03	0.62
CD (p=0.05)	0.007	0.047	0.081	0.059
M_1 (Mulching)	0.04	3.83	4.41	0.93
M_2 (No Mulching)	0.05	3.07	3.80	0.74
CD (p=0.05)	NS	0.038	0.066	0.048
I_1 (Irrigation)	0.05	3.71	4.41	0.95
I_2 (No Irrigation)	0.05	3.19	3.80	0.72
CD (p=0.05)	NS	0.038	0.066	0.016

Table 5. Evapotranspiration under different dates of transplanting, mulching and irrigation levels at different phenophases of crop

Treatment	Evapotranspiration (mm)			
Date of transplanting	Transplanting	Vegetative	Heading	Harvesting
T_1	2.38	1.72	1.74	2.10
T_2	2.48	2.19	1.57	2.36
T_3	2.17	1.60	1.90	2.50
CD (p=0.05)	0.14	0.32	0.13	0.13
M_1 (Mulching)	2.15	1.67	1.66	2.26
M_2 (No Mulching)	2.53	2.00	1.82	2.37
CD (p=0.05)	0.11	0.26	0.11	0.10
I_1 (Irrigation)	2.27	1.46	1.61	2.16
I_2 (No Irrigation)	2.42	2.21	1.87	2.48
CD (p=0.05)	0.11	0.26	0.11	0.10

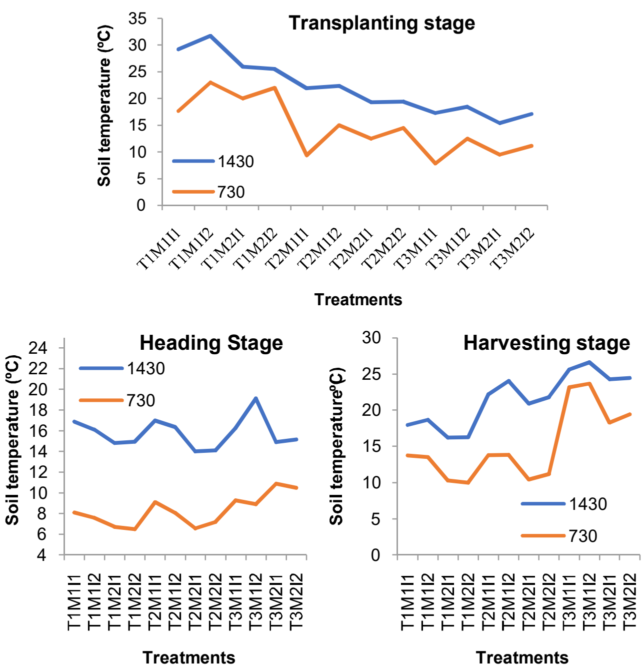

Fig. 1. Soil temperature under different dates of transplanting at 0730 and 1430 hrs during different phenophases of crop

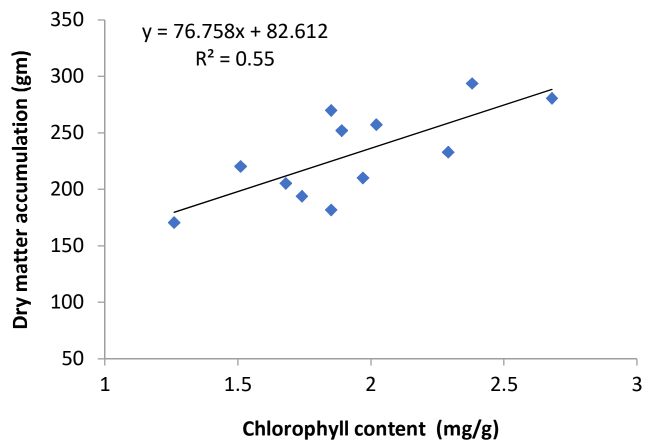

Fig. 2. Relationship between dry matter accumulation and chlorophyll content at the heading stage of broccoli

sowing which may be due to a decline in photosynthetic rate and poor leaf development leading to lower chlorophyll content.

CONCLUSION

The study concluded that under mid-hill sub-humid agroclimatic conditions, warming scenarios might negatively impact broccoli growth and yield. From transplanting onward, higher levels of photosynthetically active radiation, relative humidity, soil moisture, and leaf area index were observed in the timely-sown crop than in the late-sown crop. The study concluded that higher dry matter accumulation and leaf area index will increase PAR and chlorophyll content and improve crop quality. The control of irrigation and mulching, as well as adjustments in the date of planting, can all be used as efficient adaptation measures to reduce field crop sensitivity to extreme weather.

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Genetic Variability and Association Among Chilli Genotypes for Quantitative and Qualitative Traits

Garima Verma, Amit Vikram[1], Meenu Gupta[1] and R.K. Dogra[2]

Department of vegetable Science, Punjab Agricultural University, Ludhiana-141 004, India
[1]Department of Vegetable Science, [2] Department of Fruit Science,
Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, India
E-mail: garima-19102001@pau.edu

Abstract: A set of twenty-one breeding lines of chilli were screened for genetic variability, heritability and genetic advance for yield and related traits. A total of eight quantitative and two qualitative characters were studied including capsaicin content in the green chillies and the incidence of phytophthora fruit rot. Sufficient genetic variability was found for all characters. Screening for incidence of phytophthora fruit rot revealed that no genotype was completely resistant while 17 were moderately resistant and 4 were susceptible. Among all the genotypes, UHF-CHI-13 was superior in terms of yield with second-highest total capsaicin content and was least affected by phytophthora fruit rot. Correlation and path analysis at the green fruit stage for green fruit yield indicated that correlation between green fruit yield per plant and number of fruits per plant (0.842), green fruit breadth at middle (-0.634) and total capsaicin content in green chilli (-0.067) was due to the direct effect of these characters revealing true relationship between them. Thus, direct selection for these characters will be effective for yield improvement.

Keywords: Chilli, Correlation, Genetic variability, Path analysis

Chilli is a vital vegetable and spice crop in India because of its widespread use and richness of important nutrients and bioactive compounds with antibacterial, antioxidant, antiviral, anti-inflammatory, and anticancer properties (Mi et al 2022, Malik et al 2022). It is a solanaceous crop native to the American tropics, cultivated for its green, red, or dried berries. The two most significant commercial attributes of Indian chillies are their colour and pungency levels. The colour of chilli fruits is primarily conferred by capsanthin and capsorubin, which have considerable oxygen scavenging qualities and hence are the basis for its antioxidant nature, whilst the pungency is imparted by an active key compound 'capsaicinoids,' an alkaloid found in the placenta that may directly scavenge several free radicals (Antonious et al 2009, Nishino et al 2016, Stewart et al 2007). India is the world's largest producer, consumer and exporter of chilli with open-pollinated varieties dominating the total crop-grown area followed by hybrid varieties. Crop yield in India is low despite the vast amount of land under cultivation (Singh et al 2022). There is a vast spectrum of genetic diversity present in India. Thus, it is crucial to evaluate the genetic stock's potential and to have a thorough understanding of the genetic makeup of the genotypes and the heritable proportion of significant traits. To scale up such low yielding genotypes, it is essential to understand the underlying genetic make-up, variability, and interrelationships between key traits as well as yield components. Therefore, the present study was initiated to evaluate the twenty-one genotypes as part of a chilli improvement programme under hills of Himachal Pradesh.

MATERIAL AND METHODS

The experiment was conducted at Dr Yashwant Singh Parmar University of Horticulture and Forestry Nauni, Solan. A total of 21 genotypes namely Gundu-I and II, DKC-8, UHF-CHI-1 ,2, 3, 5, 7, 8, 9,10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and UHF Selection 4 were used for the screening. The nursery was sown in March 2018 followed by transplanting in the first week of May 2018 at a distance of 45cm×45cm with three replications in randomize complete block design. Observations were recorded for eight quantitative and two qualitative traits namely days to green fruit maturity, number of green fruits per plant, average green fruit weight (g), green fruit length (cm), green fruit breadth at the middle (cm), green fruit yield per plant (g), total capsaicin content (%) in green chilli (Sadasivam and Manickam 1996), fruit colour at mature green stage (as per the Royal Horticulture Society colour charts), fruiting habit and incidence of phytophthora fruit rot. The disease reaction for individual plants was derived using following scale (Sharma and Kumari 2014).

Grade	Fruit rot incidence (%)	Disease reaction
1	0.0 - 5.0	Resistant (R)
2	5.1 - 25.0	Moderately resistant (MR)
3	25.1- 50.0	Susceptible (S)
4	>50.0	Highly susceptible (HS)

Statistical analysis: The data on different traits was subjected to statistical analysis using SPSS 16.0 software to estimate GCV, PCV, Heritability and Genetic gain (%). GCV and PCV obtained were classified as low (0–10%), moderate (10–20%) and high (>20%) (Shivasubramanian and Menon 1973), heritability as low (0–30%), moderate (31–60%) and high (>60%) (Burton and Devane 1953) and genetic gain as low (0–25%), moderate (25–40%) and high (>40%) (Johnson et al 1955). To find out the nature of the association between the traits, correlation analysis (Al-Jibouri et al 1958) and path analysis (Dewey and Lu 1959) were computed.

RESULTS AND DISCUSSION

The presence of sufficient and significant genetic variability for all the traits is was observed (Table 1). Variation in fruit colour at the green stage and fruiting habit was also observed among the genotypes (Table 2).

Mean performance of genotypes: The genotype UHF-CHI-9 was earliest to mature (63.33 days) and had highest average green fruit weight (7.94 g) while UHF-CHI-13 produced the highest number of green fruits (198.89) and green fruit yield per plant (342.53g/plant). The maximum fruit length (14.92 cm) was in genotype UHF-CHI-8 and maximum fruit breadth at the middle (2.31 cm) was in Gundu-2. DKC-8 had the highest total capsaicin content in green chillies followed by UHF-CHI-13. The incidence of phytophthora fruit rot was highest in UHF-CHI-8 followed by UHF-Selection-4 whereas UHF-CHI-13 had the least. No genotype was completely resistant to the disease whereas, most of the genotypes i.e., 17 were moderately resistant and 4 were susceptible. Wide variation for these characters were also observed by various researchers (Shrishat et al 2007, Sarkar et al 2009, Amit et al 2014 and Pandiyaraj et al 2017).

Genetic variability parameters: The PCV was bigger than GCV (Table 3) suggesting the apparent variation in the characteristics was caused not just by genotype but also by environmental influences. However, the difference in PCV and GCV values was small which revealed that the environment has little influence on phenotypes and that phenotypic variability can be leveraged for improvement. Furthermore, the variances ranged from low to high, with high GCV and PCV for the number of fruits per plant, average green fruit weight, green fruit breadth at middle, green fruit length, green fruit yield per plant and total capsaicin content in green chilli indicating towards availability of significant variation for genetic improvement of chilli, despite the fact that PCV was greater than GCV. This level of variation in these characteristics allows for successful genotype selection and development. (Amit et al 2014, Mishra et al 2015, Pandiyaraj et al 2017). PCV and GCV was low in days to green fruit maturity therefore, cannot be utilized for selection. Further, to estimate the inheritance of characters, heritability was estimated which ranged from 90.7–94.85% offering a high probability of fixing of a character by selection (Table 3). Heritability alone is not sufficient to determine the effectiveness of selection as it includes both fixable and non-fixable variance thus, is combined with the estimates of genetic gain to increase the significance from the point of expected gain and type of selection method to be followed. High heritability with high genetic gain was observed for the number of green fruits per plant, average green fruit weight, green fruit yield per plant, green fruit breadth at middle, green fruit length, and total capsaicin content in green chilli (Table 3). High heritability with high genetic gain contributes to the additive gene effect of these traits suggesting the suitability of selection for improvement in contrast to low genetic gain observed for days to green fruit maturity similar to previously observed by Amit et al (2014) for days to green fruits maturity.

Correlation analysis: The genotypic correlation coefficient was larger than the phenotypic correlation coefficient, showing a significant underlying relationship between these traits under examination (Table 4). Earlier researchers reported similar findings (Chattopadhyay et al 2011, Kumar et al 2012, Krishnamurthy et al 2013). Total capsaicin content in green chilli showed a positive significant correlation with the number of green fruits per plant and green fruit breadth at the middle while a negative significant correlation with the fruit length and average green fruit weight suggesting that

Table 1. Analysis of variance (ANOVA)

Source of variation	df	X1	X2	X3	X4	X5	X6	X7
Replication	2	60.143	1.53	0.02	5.164	0.168	0.004	0.00003
Treatment	20	380.45*	3521.06*	4.88*	13464.87*	26.032*	0.582*	0.0239*
Error	40	5.61	4.95	0.015	9.67	0.149	0.002	0.00005

X1 Days to green maturity
X2 No. of green fruits per plant
X3 Average green fruit weight (g)
X4 Green fruit yield per plant
X5 Green fruit length (cm)
X6 Green fruit breadth at the middle (cm)
X7 Total capsaicin content (%)

selection for genotypes with a greater number of small-sized fruits would be a most suitable selection criterion for high pungent fruits. The green fruit length showed a positive significant correlation with the average green fruit weight whereas, days to green fruit maturity showed a negative significant correlation with average red fruit weight and green fruit length. These results were in harmony with earlier studies (Kumar et al 2003, Krishnamurthy et al 2013, Amit et al 2014 and Verma et al 2022). Average green fruit weight also showed a positive significant correlation with green fruit length. Bijalwan and Mishra (2016) also found a positive significant relationship between average fruit weight and fruit length.

Path analysis: Path analysis revealed high positive direct effect (0.817) of number of green fruits per plant on green fruit yield per plant followed by average green fruit weight (0.363) while green fruit breadth at the middle (-0.372), days to green fruit maturity (-0.314), green fruit length (-0.241) and total capsaicin content in green chilli (-0.129) showed a high negative direct effect on green fruit yield per

Table 2. Mean performance of genotypes for different traits under study

Genotypes	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
UHF-CHI-1	78.67	86.06	2.39	138.54	5.73	0.9	0.09	Green group 143 A	Drooping	15.67 (4.08)
UHF-CHI-2	83.33	84.2	2.86	176.64	5	0.89	0.06	Yellow green group 144 A	Drooping	19.39 (4.52)
UHF-CHI-3	79.67	105	3.36	243.96	7.8	1.13	0.07	Green group 141 A	Drooping	23.74 (4.97)
UHF-CHI-5	79.33	70.71	3.78	182.56	9.67	1.02	0.07	Green group 143 A	Drooping	15.18 (4.02)
UHF-CHI-7	72.33	95.54	4.3	290.92	10.8	1.14	0.06	Green group 144 A	Drooping	13.94 (3.86)
UHF-CHI-8	78.33	135.13	2.32	237.1	14.92	0.69	0.08	Green group 141 B	Drooping	12.98 (3.74)
UHF-CHI-9	63.33	30.93	7.94	107.39	13.09	1.54	0.04	Yellow green group 145 B	Drooping	29.84 (5.55)
UHF-CHI-10	67.67	79.93	3.56	188.31	8.2	0.89	0.05	Green group 139 A	Drooping	27.98 (5.38)
UHF-CHI-11	82	121.29	2.67	250.51	7.11	0.74	0.08	Green group 135 A	Drooping	20.22 (4.61)
UHF-CHI-12	77.67	87.85	3.04	216.08	5.9	0.9	0.07	Green group 143 B	Upright	14.61 (3.95)
Gundu-1	71.67	62.93	2.1	97.86	2.12	2.19	0.11	Green group 143 B	Drooping	24.07 (5.01)
Gundu-2	73.33	68.37	2.25	102.58	3.25	2.31	0.11	Green group 143 B	Drooping	25.04 (5.10)
UHF-CHI-13	101.67	198.89	1.95	342.53	5.66	0.68	0.1	Green group 143 B	Upright	8.53 (3.09)
UHF-CHI-14	99	111.93	3.14	278.81	8.41	0.77	0.06	Yellow green group 144 A	Drooping	17.46 (4.30)
UHF-CHI-15	89.33	109.97	2.64	229.39	8.33	1.03	0.07	Yellow green group 144 C	Drooping	15.95 (4.12)
UHF-CHI-16	88.67	77.28	2.83	154.84	7.93	1.01	0.08	Green group 141 B	Drooping	24.55 (5.06)
UHF-CHI-17	97.67	87.13	2.83	177.68	7.47	1.02	0.08	Green group 143 A	Drooping	23.06 (4.91)
UHF-CHI-18	93	75.67	2.81	139.85	7.71	1.01	0.06	Green group 143 A	Drooping	24.90 (5.09)
UHF-CHI-19	101.33	79.81	2.45	123.25	7.62	0.98	0.08	Green group 143 B	Drooping	22.44 (4.84)
UHF Selection 4	72	47.8	4.44	133.36	9.94	1.51	0.05	Green group 141 A	Drooping	28.06 (5.39)
DKC-8	89	90.06	2.92	192.91	6.03	0.85	0.11	Yellow green group 144 A	Upright	12.46 (3.67)
Mean	82.81	90.78	3.17	190.72	7.75	1.1	0.08			20(4.54)
CD (p=0.05)	3.91	3.67	0.2	5.13	0.64	0.07	0.005			

* Figures in the parenthesis are square root transformed values.X1-7:See Table 1 for details, X8: Fruit colour at green fruit stage, X9:Fruiting habit, X10: Incidence of phytophthora fruit rot

Table 3. Estimates of genetic variability parameters for different traits of chilli genotypes

Characters	PCV (%)	GCV (%)	Heritability	Genetic gain (%)
Days to green fruit maturity	9.8L	9.5L	90.7H	23.58L
No. of green fruits per plant	33.79H	33.71H	94.58H	74.21H
Average green fruit weight (g)	36.37H	36.19H	94.12H	76.12H
Green fruit length (cm)	34.24H	33.92H	93.31H	64.52H
Green fruit breadth at the middle (cm)	36.01H	35.8H	93.97H	72.49H
Green fruit yield per plant (g)	31.15H	31.12H	94.79H	68.59H
Total capsaicin content in green chilli (%)	22.83H	22.52H	92.67H	52H

Table 4. Correlation analysis among yield and yield contributing traits

Characters		X_1	X_2	X_3	X_4	X_5	X_6
X_2	G	0.537*					
	P	0.525*					
X_3	G	-0.530*	-0.537*				
	P	-0.516*	-0.534*				
X_4	G	0.344*	0.842*	-0.191			
	P	0.339*	0.841*	-0.189			
X_5	G	-0.189	-0.026	0.573*	0.204		
	P	-0.185	-0.025	0.565*	0.200		
X_6	G	-0.508*	-0.575*	0.165	-0.634*	-0.340*	
	P	-0.488*	-0.570*	0.163	-0.630*	-0.335*	
X_7	G	0.255*	0.299*	-0.680*	-0.067	-0.620*	0.256*
	P	0.242	0.293*	-0.669*	-0.065	-0.609*	0.254*

*Significant at 5% level of significance; See Table 1 for details

Table 5. Path analysis depicting direct and indirect effect of different traits on yield

Characters	X_1	X_2	X_3	X_4	X_5	X_6	GCC
X_1	-0.322	-0.173	0.171	0.061	0.164	-0.082	0.344*
X_2	0.458	0.854	-0.458	-0.022	-0.491	0.255	0.842*
X_3	-0.207	-0.209	0.39	0.224	0.064	-0.265	-0.191
X_4	0.052	0.007	-0.157	-0.273	0.093	0.169	0.204
X_5	0.15	0.17	-0.049	0.1	-0.296	-0.076	-0.634**
X_6	-0.036	-0.043	0.097	0.088	-0.036	-0.142	-0.067

* Significant at 5% level of significance, Residual effect = 0.115, GCC Genetic coefficient of correlation
X_1 = Days to green fruit maturity; X_2 =No. of green fruits per plant; X_3 =Average green fruit weight (g); X_4 =Fruit length at green fruit stage (cm); X_5 =Fruit breadth at the middle (cm); X_6 =Total capsaicin content in green chilli (%)

plant. High positive indirect effect was observed for days to green fruit maturity (0.439), followed by total capsaicin content in green chilli (0.244) via number of green fruits per plant. The residual effect at the genotypic level was observed to be 0.11, which signifies the relevance of selected characters in representing total genetic variability. Such results were also observed by earlier researchers (Patel et al 2015, Pujar et al 2017, Murmu et al 2017 and Vidya et al 2018). Correlation and path analysis at green fruit stage for green fruit yield indicated that correlation between yield and number of fruits per plant, green fruit breadth at middle and total capsaicin content in green chilli was due to the direct effect of these characters revealing true relationship between them. Thus, direct selection for these characters will be effective for yield improvement. Correlation between yield and days to green fruit maturity was due to indirect effect via number of green fruits per plant. Thus, indirect selection for this trait can be followed. However, average green fruit weight had the positive direct effect with yield but the correlation was negative. Direct selection for this character can be practiced to reduce the undesirable indirect effects.

CONCLUSION

There was significant variation for all the characters under study. Among all the genotypes, UHF-CHI-13 was found superior in terms of yield. It also gave the second-highest total capsaicin content and was least affected by phytophthora fruit rot. Correlation and path analysis for green fruit yield indicated that the correlation between green fruit yield and number of fruits per plant, green fruit breadth at middle and total capsaicin content in green chilli was due to the direct effect therefore, direct selection for these characters will influence the yield.

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Augmentation of Rooting and Shooting in Stem Cuttings of Dragon Fruit [*Hylocereus Costaricensis* (Web.) Britton and Rose]

Pankaj Kumar Meena, Sutanu Maji* and Meezan Ali

Department of Horticulture, Babasaheb Bhimrao Ambedkar University, Lucknow-226 025, India
**E-mail: majisutanu@gmail.com*

Abstract: Introduction of new remunerative crop in horticultural diversity is now required to boost farmers' income. Dragon fruit is one of the new exotic fruits cum ornamental crops which is getting new market dimention in Indian market, however, mostly imported due to less production area. To enhance its production rapid large scale multiplication is needed to establish more orchards. Fewer studies have been done in India to promote successful healthy planting materials of dragon fruit. In this experiment an attempt has been made to study influence of IBA on rooting and shooting of stem cuttings of dragon fruit to produce quality planting materials easily. The application of IBA on stem cutting has a positive role for success and among the various concentrations 3500 ppm IBA is the best for stem cutting of dragon fruit at subtropical climatic condition in respect of more number, length and diameter of roots and newly emerged shoots.

Keywords: Cutting, Dragon fruit, *Hylocereus*, Propagation

Dragon fruit (*Hylocereus spp.*) is one of the newly introduced exotic minor fruit crop in India. It is botanically climbing vine cactus with areal roots that bear glabrous attractive berry with large scale is the main character of this fruit (Fournet 2002), under the cactaceae family. It is native of tropical forest region of Mexico and Central and South America (Mizrahi 2014). Generally, there are four major groups of dragon fruit namely *Hylocereus undatus* (white flesh with pink skin), *H. costaricensis* (with violet red flesh and pink skin), *H. polyrhizus* (red flesh with red to pink skin), *H. (Selenicerus) megalanthus* (white flesh with yellow skin). Dragon fruit touted for their broad aspects of health benefit potentials and medicinal properties which increase its demand worldwide very rapidly including India. The 95 % of its demand in Indian market is meeting up by importing from other countries, because of very less cultivation in India except few pockets (Ali et al 2018, Maji 2019). Thus, new orchard development of dragon fruit is necessary to increase cultivation area and for this rapid propagation of quality planting material is need of hour. Propagation through seed is easy but, germinated plants are not true to type because of cross pollination and take more time to bear. Therefore, dragon fruit is generally propagated vegetatively through stem cuttings for easy and rapid multiplication. Use of bioregulators helps for better rooting success and auxins are well known to stimulate rooting of cuttings (Hartman et al 2002). It has been repeatedly confirmed that auxin is required for initiation of adventitious root on stem and division of first root initial cell are dependent upon either applied or endogenous auxins like IBA. However, concentration of root promoting hormone like IBA varying from 100 ppm to 10000 ppm in dragon fruit stem cutting as reported by various scientists in different agro-climatic zones (Seran and Thiresh 2015, Ahmad et al 2016, Siddiqua et al 2019). Hence, this investigation was conducted to find out the influence of IBA on root and shoot characteristics of dragon fruit stem cuttings under subtropical climate at Lucknow of Uttar Pradesh, India.

MATERIAL AND METHODS

The present study was conducted under poly house structure at Babasaheb Bhimrao Ambedkar University, Lucknow, UP, India, geographically which is at an elevation of 123 meter above Mean Sea Level (MSL) in the subtropical climate of central Uttar Pradesh at 26˚55´ North latitude and 80˚59´ East longitude. Cuttings were experimented for rooting during month of September, 2018 when average temperature was about 36°C and had high humidity.

Preparation of stem cutting: Cuttings were collected from fresh, mature, undamaged (free from insect, pest, disease attack and physical injury) two year old mother vines [*H. costaricensis* (Web.) Britton and Rose] from Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India due to its attractive pink coloured fruits. A slanted cut was made on the stem end of cutting for more rooting and easy identification of distal end and proximal end of cutting. Length of cuttings was maintained at 25 ± 2 cm.

Preparation of rooting media: Sand, soil and farm yard manure were mixed in the ratio of 2:1:1 thoroughly by hand

and spade. Prepared rooting media was filled in polyethylene bags of 15 × 9 cm size with 235 gauges.

Treatment of cuttings: The experiment was laid out in a Complete Randomized Design (CRD) with 11 treatment combinations which are replicated thrice. Selected cuttings with uniform size were treated with Indole - 3 - Butyric Acid (IBA), purchased from Spectrochem Pvt. Ltd. Mumbai (India) at different concentrations (T_1 – 0 ppm Control, T_2 - 500 ppm, T_3– 1000 ppm, T_4 – 1500 ppm, T_5 – 2000 ppm, T_6 – 2500 ppm, T_7 – 3000 ppm, T_8 – 3500 ppm, T_9 – 4000 ppm, T_{10} – 4500 ppm, T_{11} – 5000 ppm). The stock solution (10000 ppm) was used to prepare the required concentration of solution according to treatment. The cuttings were treated with 2% Bavistin solution and dried in shade, cool place before IBA treatment. After treatment cuttings were planted in poly bags containing rooting media, keeping indentation margin upside.

Observations recorded: Sprouted cuttings were randomly selected for recording the observation from each replication of every treatment throughout the study on the destructive basis. Observations were recorded at 30, 60, 90 days after treatment (DAT) of stem cutting. Root length, number of roots per cutting, diameter of root was measured. Shoot characteristics were recorded at 90, 120 and 150 DAT of stem cutting in respect of length of newly emerged shoot, number of shootlet / cutting, shoot width.

Statistical analysis: The statistical analysis of recorded data was done using OPSTAT software run by CCSHAU, Hisar, India (Sheoran et al 1998) and treatment mean were compared with critical difference at 5 % level of significance.

RESULTS AND DISCUSSION

Number of initiated root/ cutting: The numbers of new initiated roots are significantly influenced by application of rooting hormone IBA at 30, 60 and 90 DAT. Maximum number of roots were recorded 3.67, 6.00 and14.00, respectively in treatment T_8 (IBA @ 3500 ppm) at 30, 60 and 90 days after planting compared to minimum in control (1.33, 4.33,7). Control treatment showed minimum number of roots at every stages of growth. Induction of roots number in cuttings is might be due to presence of food material in cuttings and due to effect of plant growth hormone stimulated the cambial activity in treated stem cuttings. Acceleration in root initiation is increased due to IBA treatment, it induced water uptake capacity of roots and cell wall elasticity further may have accelerated cell division and in turns into number of roots in stem cuttings of dragon fruit (Ayesha and Thipesh 2018). The increased average number of root per cutting by application of IBA was also observed in earlier findings (Seran and Thiresh 2015, Ahmad et al 2016, Dhruve et al 2018). Thus, application of the different concentration of IBA positively influenced number of initiated roots per cutting as it influence the initiation of roots in cutting.

Length of roots: Maximum average length of root showed significant difference between different IBA treatment combinations. Maximum length of root (3.91, 2.70, 15.17 cm) was recorded in treatment with IBA at 3500 ppm in compared to minimum length (2.70, 9.26, 12.27 cm) in control at 90, 120, 150 DAT, respectively. The results were consequences with the findings of Seran and Thiresh (2015), Ayesha and Thippesha (2018) and Dhurve et al *(*2018). It might be due to

Table 1. Effect of different concentration of IBA on root characteristic of dragon fruit stem cuttings

IBA concentration (ppm)	Average number of roots/cutting			Average length of roots (mm)			Average diameter of roots (mm)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
0 ppm (Control)	1.33	3.33	7.00	2.70	9.26	12.27	0.17	0.66	0.73
500	1.67	4.00	10.33	2.77	9.56	12.28	0.29	0.67	1.13
1000	3.00	4.33	12.00	2.74	9.33	12.68	0.27	0.76	1.36
1500	2.67	4.33	9.00	3.12	9.51	14.07	0.51	0.67	1.14
2000	3.00	5.00	12.00	3.16	9.61	14.32	0.49	0.85	1.23
2500	2.00	4.33	11.00	3.60	11.02	12.41	0.41	0.68	1.39
3000	2.33	5.00	10.00	3.59	11.03	14.44	0.49	0.87	1.56
3500	3.67	6.00	14.00	3.91	11.17	15.48	0.83	0.96	1.86
4000	3.00	5.33	12.00	3.48	10.22	15.34	0.43	0.74	1.32
4500	2.33	4.67	13.00	3.74	10.56	12.96	0.53	0.95	1.36
5000	3.00	4.00	9.00	3.59	10.49	13.52	0.39	0.90	1.26
CD (p = 0.05)	N/S	1.36	1.80	0.52	1.23	1.91	0.31	N/S	0.43

Note: DAT - Days after treatment, N/S- Non significant

Table 2. Effect of different concentration of IBA on shoot characteristics of dragon fruit stem cuttings

IBA concentration (ppm)	Average number of shoots/cutting			Average length of shoots (mm)			Average width of shoots (mm)		
	90 DAT	120 DAT	150 DAT	90 DAT	120 DAT	150 DAT	90 DAT	120 DAT	150 DAT
0 ppm (Control)	0.47	1.10	1.67	71.42	98.55	112.23	24.64	29.94	32.30
500	0.90	1.10	1.70	81.47	103.52	115.17	25.61	30.63	32.65
1000	1.13	1.70	2.03	106.36	125.17	132.38	25.66	32.42	33.34
1500	1.37	1.43	1.73	104.04	126.47	140.88	30.73	31.76	33.34
2000	1.10	1.50	2.23	92.33	115.05	134.58	31.26	31.62	33.08
2500	1.40	1.73	2.20	112.10	115.84	130.75	26.59	31.63	32.85
3000	1.40	1.70	2.10	117.55	136.54	154.73	31.65	32.16	40.50
3500	1.43	2.17	2.57	121.05	140.54	161.34	31.95	34.40	42.06
4000	1.00	1.33	2.30	98.78	135.38	152.93	28.25	33.79	40.06
4500	1.10	1.27	1.80	101.49	117.38	135.83	29.04	31.48	34.58
5000	1.30	1.53	1.77	102.52	117.53	130.69	26.28	33.42	34.48
CD (p=0.05)	N/S	N/S	N/S	1.46	1.40	1.58	1.43	1.82	1.55

effect of auxin because rooting was favored by a high C/N ratio and presence of higher percentage of starch, sucrose, reducing sugars. The auxin treatment markedly enhanced starch depletion and the same was correlated with enhanced rooting and triggering elongation process.

Average root diameter: Maximum diameter (0.83, 0.96, 1.86 mm) of root was in the cuttings when treated with IBA @ 3500 ppm as compared to minimum root diameter (0.17.0.66, 0.73 mm) observed in control, respectively at 30,60, and 90 DAT. Ahmed et al *(*2016) also recorded average diameter of root as similar to present result. This might be due to IBA, which acted as a root promoting hormone influencing root primordia and length of root with number of root. Thus, IBA positively and significantly affect the root diameter also. Rana and Babita (2016) also reported the beneficial effect of IBA on rooting of kiwi fruit.

Number of shootlet/ cutting: Numbers of new shootlet per cutting were affected positively but non- significantly by treatment of plant growth hormone (IBA). However, maximum number of new shootlet were (1.43, 2.17, 2.57) recorded on cuttings treated with IBA @ 3500 ppm (T_8) while, minimum number of new shootlet (0.47, 1.10, 1.67) were at untreated cuttings (control) at 90, 120, 150 DAT, respectively. Similar kind of result was noticed by Singh (2017) in pomegranate and by Baghel et al (2016) in guava. IBA might activate dormant bud and by the activation of hydrolytic enzymes, which acted upon reserve food material stored in the cutting, the supply of respiratory substrates to glycolytic enzymes leads to release of energy and helps in sprouting and production of new shoot.

Length of newly emerged shoot: Lengths of newly emerged shootlet were significantly different among the treatments. Application of IBA at 3500 ppm (T_8) showed maximum length of new shootlet (121.05, 140.54, 161.34 mm) at 90, 120 and 150 DAT, respectively, while minimum length of shoot was observed (71.42, 98.55, 112.33 mm) in control treatment. It might be due to that length of newly emerged shootlet is positively influenced by indole-3-butyric acid since it increase endogenous level of auxin and auxin are well known for stimulation of root and shoot in plants (Hartman et al 2012). Therefore, auxin might positively increase length of new shoot in stem cutting of dragon fruit. Earlier researchers Kumawat et al (2014), Seran and Thiresh (2015), Ahmad et al *(*2016) and Dhurve et al (2018) also found similar results.

Width of new shoot: The significantly higher shoot width (31.95, 34.40, 38.76 mm) was in cuttings under treatment T_8 (IBA @ 3500 ppm), while minimum shoot width (24.64, 29.94, 32.30 mm) respectively at 90, 120 and 150 DAT was seen in control treatment. These results corroborated with the

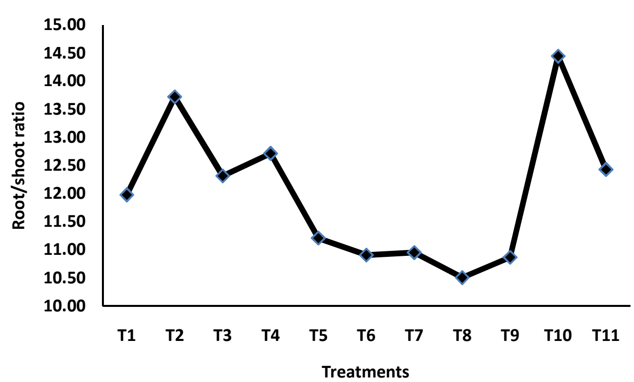

Fig. 1. Root/shoot ratio (number basis) of newly emerged rooted cuttings of dragon fruit at 150 DAT

findings of Ha et al (2014) which might be due to the fact that its influence on cell division and enlargement which directly enhanced width of shoot also.

Root: shoot ratio: This ratio on the basis of number of roots and shoots at 150 DAT) clearly depicted that application of IBA @ 3500 ppm had low ratio indicating very good growth of root as well as newly emerged shoot as compared to other treatments (Fig. 1).

CONCLUSION

The dragon fruit stem cuttings treated with IBA at 3500 ppm was found superior in all the root and shoot growth parameters among all the treatments studied and producing healthy and vigorous plants. Therefore, Indole -3-butyric acid at 3500 ppm can be utilized for producing healthy and vigorous planting material of dragon fruit to get 100% success with superior growth through stem cutting at subtropical climatic area.

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Genetic Variability and Correlation Estimates for Morpho-Physiological Characteristics in Half Sib Progenies of *Toona ciliata*

Ranjeet Singh, Sapna Thakur*, Neha Gupta[1] and Gurvinder Pal Singh Dhillon

Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana-141004, India
[1]Department of Botany, Punjab Agricultural University, Ludhiana-141 004, India
**E-mail: sapnathakur@pau.edu*

Abstract: The study was conducted to evaluate the growth performance and physiological behaviour of half sib progenies of twenty-four genotypes of *Toona ciliata* M. Roem, under field conditions. On the basis of mean performance, seed source S5 (Salouni), S6 (Chabutra) and S2 (Kamahi Devi) exhibited outstanding performance whereas among genotypes, progenies of S_6G_{16} (Chabutra), S_5G_{15} (Salouni), S_6G_{17} (Chabutra), S_2G_4 (Kamahi Devi) and S_5G_{13} (Salouni) were superior for morphological and physiological characteristics. High heritability and moderate genetic gain were observed for leaf area, petiole length, clear bole height, carotenoids, chlorophyll a and total chlorophyll content and suggests that genotypic selection would be most effective for these traits. Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height and total chlorophyll with carotenoids and needs to be taken into consideration while doing indirect selection for the associated characters. Further, total chlorophyll, should be given weightage while selection along with other traits (carotenoids, chlorophyll a and plant height), since they are the largest contributors towards total genetic diversity in the genotypes.

Keywords: Correlation, Genotype, Heritability, Principal component, Progenies, Seed source

Genus *Toona* belongs to family Meliaceae and consists of five species i.e., *Toona sinensis*, *T. sureni*, *T. fargesii*, *T. calantas* and *T. ciliata* (Edmonds 1995). *Toona ciliata* commonly known as toon or red cedar is highly valued for its quality timber and ease of cultivation in plantations (Uppal and Singh 2010). It is a large fast growing deciduous or semi-deciduous tree commonly attaining a height of 20-30 m and a girth of 1.83 m (Orwa et al 2009). It is native to Australia and has been distributed naturally in India, Burma, Laos, Pakistan, Thailand, Malaysia, Indonesia, and China. In India, the species is distributed throughout the sub- Himalayan tract and the valleys of outer-Himalayas, plains of Assam, Madhya Pradesh, Tamil Nadu, Karnataka, Eastern and Western Ghats up to an elevation of 1200m in Western Peninsula. Toon is one of the prominent species that dominates the agricultural landscapes of the subtropical and sub-temperate Himalayas of the northwest Himalayas (Yogeshwari 2013) and is generally planted as border tree on agriculture fields and along roadside plantations in Himachal Pradesh, Uttarakhand and in some part of Punjab. *T. ciliata* exhibits adaptability to stress conditions caused by air pollution. Higher tolerance and anticipated performance index reported in *T. ciliata,* suggests its suitability for roadside plantations so as to intercept the air pollutants (Haseena and Bhardwaj 2018). Toon is one of the most valuable and appreciated timber species of tropics serving the same purpose as the pines of north temperate zones. Toon possesses important economic characteristics including a relatively short 15-year cycle; straight clean bole, good yields, and high value in the internal and external markets (Murakami 2008). The species has high potential to achieve an average annual increase of 30 m^3 ha^{-1} yr^{-1} under good cultivation conditions and management practices (Vilela and Stehling 2012). Toon wood has moderate weight, quality and hardness, and is widely used in various wood-based industries. In addition, toon leaves are excellent source of fodder during the lean period, the flowers are rich source of red dye and the bark has astringent and medicinal properties. *T. ciliata* is enriched with many biological compounds with medicinal properties. Cedrelone and dysobinin extracted from *T. ciliata* have exhibited significant cytotoxicity to cancer cells (Liu et al 2011a, 2012, Jiang et al 2012). Similarly, ethyl acetate extracts have anti-cancer effects on human breast cancer cell lines (Liu et al 2011b).

Estimating the genetic variability existing in the seed sources and among genotypes within seed sources through progeny evaluation is a prerequisite for isolating elite genotypes/ progenies which are much desired for mass propagation and achieving maximum gain in the productivity. Assessment of quantitative traits contributing towards high biomass or timber production as well as gaining an insight to the complex traits association and extracting traits with highest contribution towards the genetic variability in the population can be effective towards selection and obtaining higher genetic gain in each cycle of any tree improvement programme.

MATERIAL AND METHODS

The study was conducted at Punjab Agricultural University, Ludhiana. The area is situated at 30° 54' 26 " N latitude and 75° 47' 38" E longitude at an elevation of 247m above mean sea level, representing the central zone of Punjab. The assessment of morpho-physiological traits was performed on progeny trial of *T. ciliata* established in the year 2018, using randomized complete block design with 4 replications at a distance of 4 x 3 m in east-west (row distance) direction. The detailed list of *T. ciliata* seed sources and genotypes established in the progeny trial are presented in Table 1. The soil texture of the experimental site was clayey loam. The trial was irrigated at fortnight intervals in summers and at monthly intervals in winters. Weeding was performed at monthly intervals.

Observation on growth parameters (Plant height, clear bole height, collar diameter, straightness score, leaf area and petiole length) were recorded at the age of three years. The pigment concentration (chlorophyll a, chlorophyll b, chlorophyll a/b ratio, total chlorophyll and carotenoids) was done using dimethyl sulphoxide (DMSO) non maceration method of Hiscox and Israelstam (1979) and sugar accumulation (total soluble sugars and starch) was done using standard procedure of Dubois et al (1956). Starch content was calculated by multiplication of total glucose content from dried residue with a constant factor of 0.9. Sucrose content was determined following the method of Roe et al (1949). The genetic parameters, genotypic and phenotypic correlation coefficients and PCA were performed using online software OPSTAT.

RESULTS AND DISCUSSION

Significant variation was observed among seed sources for all the traits except stem straightness, chlorophyll a/b and sucrose content (Table 2, 3, 4). On the basis of overall performance for morphological and physiological character, seed sources S5 (Salouni) observed maximum plant height, clear bole height, collar diameter, leaf area, chlorophyll a, chlorophyll a/b, total chlorophyll, total soluble sugar and

Table 1. Details of *T. ciliata* seed sources and genotypes

Code name	Seed sources (Districts)	Genotypes	Latitude (°)	Longitude (°)	Altitude (Above msl)
S1	Talwara (Hoshiarpur, Punjab)	G1	31° 55' 52"	75° 53' 38"	380
		G2	31° 56' 20"	75°52'30"	367
		G3	31°56'55"	75°48'28"	350
S2	Kamahi Devi (Hoshiarpur, Punjab)	G4	31° 64' 23"	75° 53' 29"	368
		G5	31°54'24"	75°49'24"	330
		G6	31°59'35"	75°58'47"	394
S3	Ludhiana (Punjab)	G7	30° 50' 43"	75° 53' 12"	255
		G8	30°46'04"	75°51'27"	250
		G9	30°47'32"	75°51'11"	250
S4	Sujanpur (Hamirpur, HP)	G10	31°48'59"	76°31'3"	726
		G11	31°48'05"	76°28'06"	610
		G12	31°47'57"	76°27'58"	601
S5	Salouni (Hamirpur, HP)	G13	31° 31' 42"	76° 27' 49"	805
		G14	31°33'46"	76°28'45"	807
		G15	31°63'26"	76°28'43"	808
S6	Chabutra (Hamirpur, HP)	G16	31° 44' 27"	76° 28' 24"	750
		G17	31°44'28"	76°28'30"	749
		G18	31°44'20"	76°28"36"	740
S7	Shah Talai (Bilaspur, HP)	G19	31° 26' 09"	76° 32' 28"	610
		G20	31°27'09"	76°32"28"	613
		G21	31°26'03"	76°32'38"	618
S8	Suhari Takoli (Una, HP)	G22	31° 40' 23"	76° 14' 50"	630
		G23	31°40'12"	76°14'58"	625
		G24	31°40'23"	76°14'50"	626

starch followed by S6 (Chabutra) for collar diameter, chlorophyll a, total chlorophyll, carotenoid content, total soluble sugar and starch and S2 (Kamahi Devi) for clear bole height, stem straightness, petiole length, sucrose and starch.

In case of genotypes among seed sources progenies of S_6G_{16} recorded maximum mean value for plant height, collar diameter, straightness, chlorophyll a, total chlorophyll, carotenoid content, total soluble sugar and starch followed by

Table 2. Effect of seed source and genotypes within seed sources on growth traits of *T. ciliata* progeny

Seed source	Genotype	Growth traits					
		Plant height (m)	Clear bole height (m)	Collar diameter (cm)	Stem Straightness (1-5)	Leaf area (cm^2)	Petiole length (cm)
S1 (Talwara)	G1	3.52	1.21	7.55	4.13	47.00	8.38
	G2	3.56	1.36	7.28	4.38	43.00	9.09
	G3	3.30	1.10	7.83	4.21	50.00	10.30
	Mean	3.46	1.22	7.55	4.24	46.67	9.25
S2 (Kamahi Devi)	G4	4.01	1.99	7.19	4.88	59.00	15.24
	G5	3.35	1.33	7.25	4.15	40.00	10.08
	G6	3.32	1.47	6.68	4.31	37.00	9.46
	Mean	3.56	1.60	7.04	4.44	45.33	11.59
S3 (Ludhiana)	G7	3.64	1.11	7.15	4.19	36.00	9.30
	G8	3.73	1.11	8.88	4.31	55.00	10.98
	G9	3.58	1.26	7.93	4.38	53.00	9.63
	Mean	3.65	1.16	7.98	4.29	48.00	9.97
S4 (Sujanpur)	G10	3.43	1.57	6.28	4.00	50.00	10.04
	G11	3.49	1.43	6.73	3.94	35.00	10.53
	G12	3.25	1.29	6.10	4.31	34.00	8.48
	Mean	3.39	1.43	6.37	4.08	39.67	9.68
S5 (Salouni)	G13	4.30	1.96	9.18	4.00	46.00	10.25
	G14	3.51	1.35	6.55	4.56	54.00	9.50
	G15	4.12	1.87	7.24	4.25	55.00	11.25
	Mean	3.98	1.73	7.66	4.27	51.67	10.33
S6 (Chabutra)	G16	3.64	1.34	9.01	4.31	51.00	9.48
	G17	3.73	1.32	7.18	4.19	30.00	10.93
	G18	3.08	1.19	6.10	3.88	31.00	9.90
	Mean	3.48	1.28	7.43	4.13	37.33	10.10
S7 (Shah Talai)	G19	3.39	1.56	6.53	4.13	44.00	7.95
	G20	3.36	1.42	6.78	4.31	49.00	10.26
	G21	3.24	1.41	6.16	4.13	33.00	10.30
	Mean	3.33	1.46	6.49	4.19	42.00	9.50
S8 (Suhari Takoli)	G22	3.40	1.05	6.73	4.25	36.00	14.50
	G23	3.63	1.46	7.38	3.88	39.00	10.38
	G24	3.30	1.15	7.56	4.13	35.00	10.25
	Mean	3.44	1.22	7.22	4.08	36.67	11.71
Mean		3.54	1.39	7.22	7.22	43.42	43.42
Range		3.08-4.30	1.05-1.99	6.10-9.18	6.10-9.18	30-59	30-59
CD (p=0.05)							
Seed source		0.27	0.20	0.84	NS	3.82	3.82
Interaction (Seed source × Genotype)		0.47	0.34	1.46	0.44	6.61	6.61

S_5G_{15}, S_6G_{17}, S_2G_4 and S_5G_{13}. Since, these progenies belong to genotypes from different seed sources and had been planted under uniform experimental conditions, the variability in various morphological and physiological characters may be attributed to genotypic variation existing in these genotypes or due to genotype x environment interactions. Min et al (2017) reported that the western provenances progenies of *T. ciliata* exhibited better growth performance in terms of tree height and basal diameter in comparison to the progenies from eastern provenances.

Table 3. Effect of seed source and genotypes within seed sources on pigment concentration (mg/g FW) of *T. ciliata* progeny

Seed source	Genotypes	Pigment concentration (mg/g FW)				
		Chlorophyll a	Chlorophyll b	Chl a / chl b	Total chlorophyll	Carotenoids content
S1 (Talwara)	G1	1.84	0.471	3.94	2.61	0.105
	G2	1.83	0.483	3.85	2.61	0.108
	G3	1.56	0.427	3.70	2.48	0.104
	Mean	1.74	0.460	3.83	2.57	0.106
S2 (Kamahi Devi)	G4	1.96	0.489	4.02	2.77	0.114
	G5	1.68	0.396	4.25	2.13	0.104
	G6	1.87	0.481	3.90	2.66	0.115
	Mean	1.84	0.455	4.06	2.52	0.111
S3 (Ludhiana)	G7	1.75	0.381	4.62	2.41	0.109
	G8	1.77	0.360	4.96	2.40	0.111
	G9	1.86	0.397	4.78	2.55	0.111
	Mean	1.80	0.379	4.79	2.46	0.110
S4 (Sujanpur)	G10	1.69	0.332	5.35	2.29	0.106
	G11	2.10	0.475	4.76	2.91	0.129
	G12	2.04	0.418	4.92	2.77	0.119
	Mean	1.94	0.408	5.01	2.66	0.118
S5 (Salouni)	G13	2.03	0.404	5.76	2.75	0.122
	G14	1.91	0.378	5.34	2.59	0.120
	G15	2.00	0.469	4.62	2.79	0.121
	Mean	1.98	0.417	5.24	2.71	0.121
S6 (Chabutra)	G16	2.03	0.477	4.33	2.83	0.125
	G17	2.19	0.494	4.95	3.03	0.130
	G18	2.06	0.403	5.47	2.79	0.137
	Mean	2.10	0.458	4.92	2.88	0.130
S7 (Shah Talai)	G19	1.89	0.512	3.89	2.71	0.118
	G20	2.15	0.656	3.30	3.16	0.135
	G21	1.88	0.493	3.84	2.68	0.121
	Mean	1.97	0.554	3.68	2.85	0.125
S8 (SuhariTakoli)	G22	1.62	0.473	3.57	2.37	0.105
	G23	1.85	0.601	3.22	2.76	0.130
	G24	1.83	0.430	4.42	2.55	0.114
	Mean	1.77	0.501	3.74	2.56	0.117
Mean		1.89	0.454	4.41	2.65	0.117
Range		1.56-2.19	0.332-0.656	3.22-5.76	2.13-3.16	0.104-0.137
CD (p=0.05)						
Seed sources		0.14	0.07	0.82	0.19	0.006
Interaction (Seed source× genotype)		0.24	0.12	NS	0.33	0.012

Partitioning of phenotypic variation is important to understand the underlying causes of variation and thus, provides opportunities for their effective utilization for the genetic improvement of the species. The genetic variation which is heritable can be exploited for further improvement programme. The genotypic coefficient of variance (GCV %) (Table 5) was maximum for clear bole height (16.34 %) and minimum for stem straightness (3.61%) whereas the

Table 4. Effect of seed source and genotypes within seed sources on sugar accumulation content (g sugar/g FW) of *T. ciliata* progeny

Seed source	Genotypes	Sugar accumulation content (g/g FW)		
		Total soluble sugar (g glucose/g FW)	Sucrose (g sucrose/g FW)	Starch (g starch/g FW)
S1(Talwara)	G1	0.118	0.010	0.096
	G2	0.156	0.012	0.073
	G3	0.101	0.009	0.082
	Mean	0.125	0.011	0.084
S2 (Kamahi Devi)	G4	0.112	0.012	0.094
	G5	0.092	0.013	0.113
	G6	0.107	0.012	0.102
	Mean	0.104	0.012	0.103
S3 (Ludhiana)	G7	0.152	0.013	0.108
	G8	0.115	0.010	0.118
	G9	0.105	0.013	0.108
	Mean	0.124	0.012	0.111
S4 (Sujanpur)	G10	0.146	0.015	0.111
	G11	0.130	0.011	0.097
	G12	0.134	0.010	0.085
	Mean	0.137	0.012	0.097
S5 (Salouni)	G13	0.121	0.012	0.090
	G14	0.154	0.012	0.102
	G15	0.129	0.011	0.101
	Mean	0.135	0.012	0.097
S6 (Chabutra)	G16	0.166	0.012	0.113
	G17	0.143	0.013	0.074
	G18	0.133	0.012	0.101
	Mean	0.147	0.012	0.096
S7 (Shah Talai)	G19	0.148	0.011	0.105
	G20	0.100	0.011	0.082
	G21	0.134	0.009	0.118
	Mean	0.127	0.011	0.102
S8 (Suhari Takoli)	G22	0.097	0.009	0.092
	G23	0.092	0.011	0.055
	G24	0.113	0.009	0.087
	Mean	0.101	0.010	0.078
Mean		0.125	0.011	0.096
Range		0.092-0.166	0.009-0.015	0.055-0.118
CD (p=0.05)				
Seed sources		0.0248	NS	0.021
Interaction (Seed source × genotype)		0.0430	0.003	0.035

phenotypic coefficient of variation (PCV) was maximum (27.65 %) for starch content and minimum for stem straightness (8.26 %). In the present study, phenotypic coefficient of variance values was higher than genotypic coefficient of variance (GCV) for all the parameters which indicate that the expression of these traits are largely influenced by the environment, as evidenced in *Azadirachta indica* (Dhillon et al 2009) and *Melia dubia* (Kumar et al 2013).

High heritability reflects the effectiveness of phenotypic selection for a particular trait; however, it does not guarantee higher genetic gains or improvement for that trait. High heritability coupled with high to moderate genetic gain indicates that the characters were governed by additive gene action whereas, high heritability coupled with low genetic gain or low heritability with low genetic gain reflects that the traits were governed by non-additive gene action. Therefore, selection encompassing high heritability along with high or moderate genetic gain gives more realistic results as they were governed by additive type of gene action and are heritable to the next generation. High heritability with moderate genetic gain was for leaf area (76.37% and 35.01%.), petiole length (46.93% and 19.87%), clear bole height (46.30 % and 23.06 %) and carotenoids (42.89 % and 9.71 %), chlorophyll a (38.75% and 9.77%) and total chlorophyll (38.15% and 9.55%) suggesting that maximum weightage should be given to these traits during selection. Dhillon et al (2009), in their study on *Azadirachta indica* seed sources, reported moderate to high heritability and genetic gain for field emergence, clear bole height, basal diameter and stem straightness indicating the effectiveness of these characters in selection for enhancing productivity in agroforestry.

Strong genotypic and phenotypic correlation was observed for plant height with clear bole height (0.832 and 0.680); total chlorophyll with carotenoid continent (0.854 and 0.817). Table 6 indicates that the magnitude of genotypic correlation was higher than the corresponding phenotypic correlation for majority of the traits which might be due to strong inherent linkage of traits at gene level or pleiotropic effect of a gene, suggested that any change in the gene locus of one trait may alter the genetic expression of the associated traits. Lastin et al (2019) also observed that the genotypic correlation coefficient was higher than the phenotypic correlation coefficient and reported highly positive genotypic and phenotypic significant correlation of diameter at breast height with total height, crown height and crown diameter in *T. sinensis*; Similar findings were reported by Parthiban (2019), Deepanjli (2018) and Kundal et al (2020) in *Toona ciliata*, suggesting that traits with strong inter relationship must be given due emphasis for indirect selection of the below ground or biomass characters without undergoing destructive sampling of the plants.

The principal component analysis revealed that five out of thirteen components had eigen value more than unity which explained 80.74 % of the total variation (Fig. 1). The first principal component (λ1= 3.548) explicated 27.29 % of the total variability with maximum loading for variables total chlorophyll (0.963), carotenoid content (0.890), chlorophyll a

Table 5. Variability and genetic estimates for growth and physiological characters of *T. ciliata* progenies

Parameter	Mean	Range	Coefficient of variation (%)		$H^2_{b.s}$ (%)	Genetic advance	Genetic gain (%)
			Genotypic	Phenotypic			
Plant height (m)	3.54	3.08-4.30	6.63	11.57	32.91	0.28	7.92
Clear bole height (m)	1.39	1.05-1.99	16.34	23.99	46.30	0.32	23.06
Collar diameter (cm)	7.22	6.10-9.18	9.64	17.32	30.98	0.80	11.08
Stem straightness (1-5)	4.22	3.88-4.88	3.61	8.26	19.16	0.14	3.32
Leaf area (cm^2)	43.42	30.00-59.00	19.44	22.25	76.37	15.20	35.01
Petiole length (cm)	10.27	7.95-15.24	14.07	20.54	46.93	2.04	19.87
Chlorophyll a (mg/g FW)	1.89	1.56-2.19	7.61	12.23	38.75	0.184	9.77
Chlorophyll b (mg/g FW)	0.454	0.332-0.656	12.09	22.42	29.07	0.061	13.43
Chlorophyll a/b	4.41	3.22-5.76	11.19	25.25	19.64	0.45	10.22
Total Chlorophyll (mg/g FW)	2.65	2.13-3.16	7.50	12.14	38.15	0.252	9.55
Carotenoid content (mg/g FW)	0.117	0.104-0.137	7.20	10.99	42.89	0.011	9.71
Total soluble sugar (g glucose/g FW)	0.125	0.092-0.166	12.60	27.55	20.92	0.02	11.87
Sucrose (g sucrose/g FW)	0.0114	0.0091-0.0153	6.68	22.02	9.20	0.001	4.17
Starch (g starch/g FW)	0.096	0.055-0.118	9.83	27.65	12.63	0.007	7.20

(0.882) and chlorophyll b (0.717). Second principal component (λ2= 2.803) elucidated 21.56 % total variability with maximum loading for traits plant height (0.865), leaf area (0.787), clear bole height (0.685). Third principal component (λ3= 1.914) explained 14.73 % with maximum loading for total soluble sugar (0.813). Fourth principal component (λ4= 1.194) explained 9.19 per cent of total variation whereas, the fifth component (λ5= 1.036) explicated 7.97 per cent of the

Table 6. Correlation among morphological and physiological characters of *T. ciliata*

		Clear bole height	Collar diameter	Straightness score	Petiole length	Leaf area	Chlorophyll index (chl a/b)	Total chl	Carotenoid content	Total soluble sugar	Sucrose	Starch
Plant height	P	0.680**	0.613**	0.405**	0.281**	0.293**	0.006^{NS}	0.193^{NS}	0.059^{NS}	-0.045^{NS}	0.170^{NS}	0.033^{NS}
	G	0.832**	0.580**	0.039^{NS}	0.388**	0.651**	0.594**	0.116^{NS}	-0.043^{NS}	0.220*	0.371**	0.263**
Clear bole	P		0.090^{NS}	0.151^{NS}	0.121^{NS}	0.290**	-0.029^{NS}	0.107^{NS}	0.053^{NS}	-0.019^{NS}	0.055^{NS}	0.033^{NS}
	G		0.048^{NS}	0.239*	0.328**	0.448**	0.334**	0.494**	0.356**	0.154^{NS}	0.734**	-0.144^{NS}
Collar diameter	P			0.370**	0.099^{NS}	0.262**	0.084^{NS}	0.033^{NS}	-0.045^{NS}	-0.066^{NS}	0.074^{NS}	0.033^{NS}
	G			-0.332**	-0.003^{NS}	0.584**	0.144^{NS}	-0180^{NS}	-0.274**	-0.145^{NS}	0.394**	0.020^{NS}
Straightness score	P				0.277**	0.315**	-0.094^{NS}	0.073^{NS}	-0.154^{NS}	-0.097^{NS}	-0.048^{NS}	-0.036^{NS}
	G				0.511**	0.835**	-0.192^{NS}	0.104^{NS}	-0.260*	0.303**	0.198^{NS}	0.414**
Petiole length	P					0.093^{NS}	-0.209*	0.048^{NS}	-0.069^{NS}	-0.282**	-0.030^{NS}	-0.015^{NS}
	G					0.229*	-0.098^{NS}	0.018^{NS}	-0.064^{NS}	-0.523**	-0.224*	-0.184^{NS}
Leaf area	P						0.067^{NS}	0.016^{NS}	-0.141^{NS}	0.026^{NS}	0.030^{NS}	0.117^{NS}
	G						-0.002^{NS}	0.116^{NS}	-0.318**	-0.072^{NS}	0.284**	0.398**
Chlorophyll index (chl a/b)	P							-0.063^{NS}	0.100^{NS}	0.288**	0.086^{NS}	0.323**
	G							0.078^{NS}	0.360**	0.658**	0.980**	0.395**
Total chl	P								0.817**	0.167^{NS}	0.040^{NS}	-0.159^{NS}
	G								0.854**	0.318**	-0.571**	0.554**
Carotenoids	P									0.107^{NS}	0.026^{NS}	-0.059^{NS}
	G									0.359**	-0.252*	0.315**
Total soluble sugar	P										0.374**	0.326**
	G										0.155^{NS}	0.080^{NS}
Sucrose	P											0.272**
	G											0.141^{NS}

*Denotes significant at 5% level of significance **Denotes significant at 1% level of significance NS: Non-significant
G denotes genotypic correlation coefficient P denotes phenotypic correlation coefficient

Table 7. Principal components for growth and physiological characteristics in *T. ciliata*

Characters	Principal components				
	1	2	3	4	5
Plant height (m)	0.172	0.865	0.033	-0.255	-0.252
Clear bole height (m)	0.391	0.685	0.154	0.193	-0.307
Collar diameter (cm)	-0.130	0.533	-0.147	-0.768	0.027
Straightness score (1-5)	-0.109	0.583	-0.130	0.429	0.568
Leaf area (cm^2)	-0.213	0.787	-0.040	-0.062	0.303
Petiole length (cm)	-0.004	0.446	-0.535	0.428	-0.127
Chlorophyll a (mg/g FW)	0.882	0.108	0.314	-0.015	0.115
Chlorophyll b (mg/g FW)	0.717	-0.073	-0.458	0.095	0.065
Total chlorophyll (mg/g FW)	0.963	0.054	0.025	-0.028	0.193
Carotenoid content (mg/g FW)	0.890	-0.131	0.164	-0.048	-0.001
Total soluble sugar (g glucose/g FW)	0.107	0.016	0.813	-0.028	0.277
Sucrose (g sucrose/g FW)	-0.115	0.303	0.566	0.332	-0.501
Starch (g starch/g FW)	-0.505	0.118	0.495	0.081	0.253
Eigen value	3.548	2.803	1.914	1.194	1.036
Percent of variability	27.295	21.561	14.727	9.187	7.971
Cumulative percent of variability	27.295	48.855	63.582	72.769	80.740

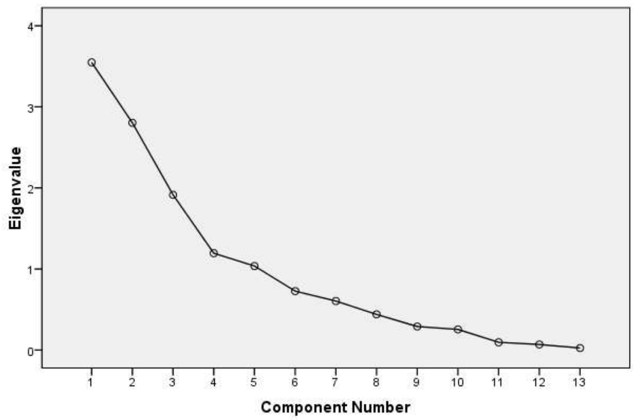

Fig. 1. Screen plot based on principal component analysis

variability. Thus, maximum weightage should be given to total chlorophyll for selection along with other traits (carotenoids, chlorophyll a and plant height), since it contributed largest variation in the total genetic variability. Principal component analysis extracted the most important traits contributing towards genetic variability in *T. ciliata* which could be used to distinguish between the genotypes and effective selection of genotypes. Danquah et al (2011) observed that 97.50 and 98.00 per cent of the total variation was explained by four principal components while working on *Khaya ivorensis* and *Khaya anthotheca,* respectively. Significant differences were found for leaf morphology in *K. ivorensis* at both, populations and ecological zones level whereas in case of *Khaya anthotheca* at population level only. Similarly, Kundu et al (2000) in *Azadirachta indica* reported that principal component analysis revealed distinct population differentiation associated with variability for plant height and survival rate of neem populations at three different sites. Further, ecoclimatic conditions at different provenances played a vital role in the differentiation of *A. indica* populations and thereby affected their survival and growth during the early stages of plant establishment.

CONCLUSION

Among seed sources, Salouni, Chabutra and Kamahi Devi whereas, among genotypes within seed sources, progenies of S_6G_{16} (Chabutra), S_5G_{15} (Salouni), S_6G_{17} (Chabutra), S_2G_4 (Kamahi Devi) and S_5G_{13} (Salouni) outperformed for various growth and physiological traits and needs to be further evaluated for performance stability. High heritability and moderate genetic gain were observed for leaf area, petiole length, clear bole height, carotenoid content, chlorophyll and total chlorophyll content. Highly significant and positive genotypic and phenotypic correlation was found for plant height with clear bole height and total chlorophyll with carotenoid content and thus may be utilized for indirect selection of the associated characters. Total chlorophyll must be given due weightage while selection, owing to maximum variable loading, along with other morphological and physiological traits (carotenoids, chlorophyll a and plant height), since they are giving maximum contribution towards total genetic diversity in *T. ciliata* progenies and would be conclusive to distinguish between the progenies and effective selection of genotypes.

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Variation in Seed Germination of *Dysoxylum binectariferum:* An Endangered Medicinal Tree Species, from Different Indian Seed Sources

Suraj R. Hosur, A. Krishna, M.R. Jagadish and R. Vasudeva

College of Forestry Sirsi, University of Agricultural Sciences, Dharwad-581401, India
E-mail: srj1419@gmail.com

Abstract: *Dysoxylum binectariferum* is an endangered medicinal tree species of India that needs urgent conservation attention. In the present study, fruits and seeds from seven different sources covering four states namely, Arunachal Pradesh, Assam, Maharashtra, and Karnataka were collected to study the variation in germination attributes. A significant variation was observed for all germination traits viz. germination per cent, germination rate, speed of germination, mean daily germination, peak value of germination, and germination value. Seed germination varied significantly (28.89-98.33%) among seven seed sources. Seeds collected from the Jog (Karnataka) location were superior in all germination attributes. Seed germination traits with altitude showed a significant positive relationship and a significant negative relationship with latitude and longitude. The information generated in the study shows that there is potential scope for further tree improvement and conservation aspects of *Dysoxylum binectariferum* across India.

Keywords: *Dysoxylum binectariferum*, Recalcitrant, Provenance, Germination, Seed traits

Dysoxylum binectariferum (family: *Meliaceae*) is an endangered small to a medium-sized tree found in the Western Ghats of India (Masur et al 2014, Sumangala et al 2016). They are widely distributed in subtropical and tropical regions. These species occur in a variety of habitats, from rainforests, and mangrove swamps to semi-deserts (Julian et al 2012). Bark is pale brown or ashy in colour, smooth or rough surface with an outer corky layer. Twigs are smooth but sturdy, leaves are alternate and imparipinnate. Flowers are 7.5 to 10.0 cm in diameter. The fruit is pear-shaped having a diameter of 4.5–5.0 cm, four-valved, yellow-orange in colour and contains a few brownish-black recalcitrant seeds. Due to the existence of dysobinin and rohitukine, *D. binectariferum* has gained global scale significance. Dysobinin, a tetranortriterpene isolated from fruits, is a central nervous system (CNS) depressant with mild anti-inflammatory activity (Singh et al 1976). The pharmacologically significant chemical rohitukine is a key natural product of this speciesand it inspired the innovation of three anti-cancer clinical candidates, flavopiridol, P-27600, and IIM-290. Among all known plant sources of rohitukine, *D. binectariferum* was produce the highest amount of rohitukine in stem bark nearly 7 percent of its dry weight. Further, the bark of the tree is be used for the treatment of foul ulcers and leprosy (Overharvesting for bark and habitat degradation have made this species endangered in India's western and north-eastern regions (Nath et al 2005, Sumangala et al 2016). In *D. binectariferum,* distribution is mainly affected by recalcitrant behaviour of seeds, rodent predation on seeds, seeds are infected by the fungus on surface litter and adverse climatic conditions such as lack of moisture for germination of fallen seeds just after the winter are major causes that hinder seed germination. One of the most important steps in tree domestication is mapping provenance variation and examining for germination traits across species distribution. However, it is difficult if the species occur in isolated patches of the interior forest has different reproductive stage timings in different regions, and is recalcitrant; losing viability in a short time frame (Gunaga et al 2020). As a result, the current study was conducted to better understand the provenance variation in seed germination traits for the endangered and recalcitrant *D. binectariferum* across its distribution in India.

MATERIAL AND METHODS

The mapping of *D. binectariferum* populations was undertaken across India. Total seven populations covering four states were earmarked for the study (Table 1, Fig. 1). In each population, five superior trees were marked and from each tree 75 fruits were collected. Trees were coded with source and tree number ex. JT1 means First numbered tree from Jog source. Since there is a variation in fruit maturity between Western Ghat and North-Eastern region, matured fruits were collected at different time i.e., 2^{nd} fortnight of January 2022 from Western Ghat and 1^{st} fortnight of March

2022 from North-East India . After collection, fruits were opened, black pulpy seed coat covered seeds were separated. Then these seeds were washed thoroughly in water to remove the pulpy seed coat and to get green seeds. Germination trials were laid out in the sand bed of nursery of College of Forestry, Sirsi. For each population, 120 seeds (40 seeds of 3 replications) were sown following a completely randomised design (Plate 1, 2). Number of seeds germinated was monitored everyday up to 60 days after sowing. Emergence of plumule above the soil followed by opening of cotyledon leaves was considered as germination. Based on daily germination count, Germination per cent was calculated by using International Seed Testing Association guidelines (Anonymous 2010) as proportion of seeds germinated from the total number of seeds sown and expressed as per cent. Germination speed (GS) was estimated using following formula given by Czabator (1962). GS = n1/d1 + n2/d2 + n3/d3 + ……; where, n = number of germinated seeds, d = number of days. Mean daily germination (MDG) was estimated as total number of germinated seeds divided by total number of days taken for germination. Peak value (PV) was estimated as highest number of seeds germinated in a given day divided by the number of days at this peak value. Germination value (GV) was estimated (Czabator 1962). GV=PV X MDG, where PV is peak value and MDG is mean daily germination. Data were subjected to statistical analysis using Operational Statistic software performed for all the studied parameters.

RESULTS AND DISCUSSION

Dysoxylum binectariferum is a recalcitrant seed-bearing tree species found in the Western Ghats and North-Eastern parts of India. Fruit maturity occurs at different times in

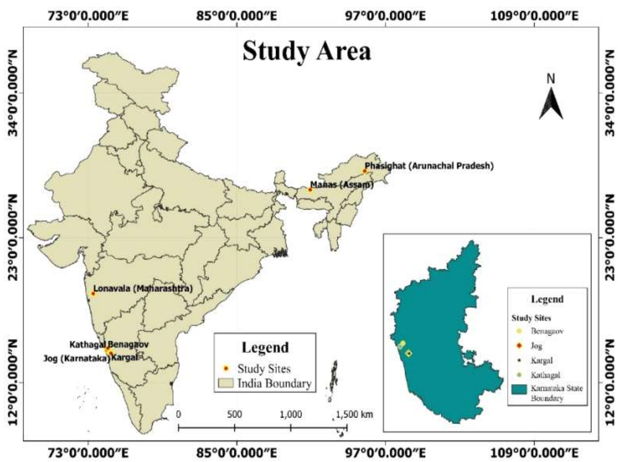

Fig. 1. Location of the study sites

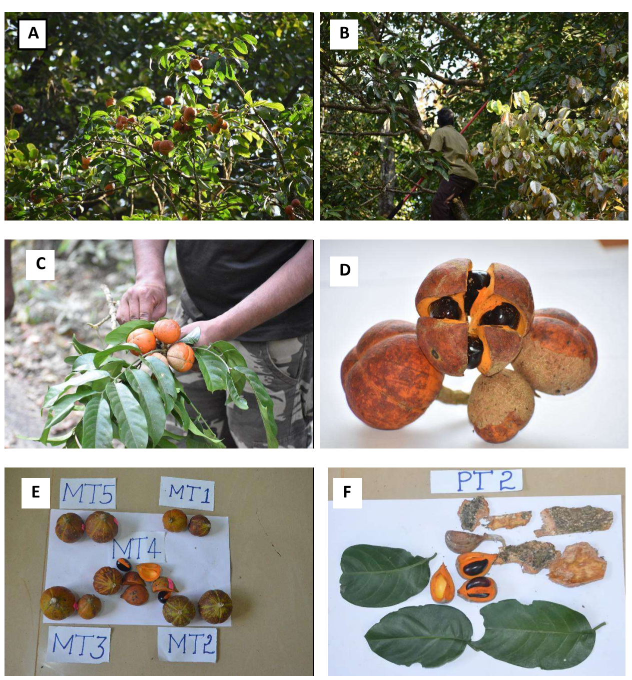

Plate 1. A: Fruits bearing branches, B: Collection of fruit using tree pruner, C, D: Pictorial representation of Fruits of *D. binectariferum,* E: Fruit samples from Manas, F: Fruit, Seed, Bark and Leaf samples of Phasighat tree number two

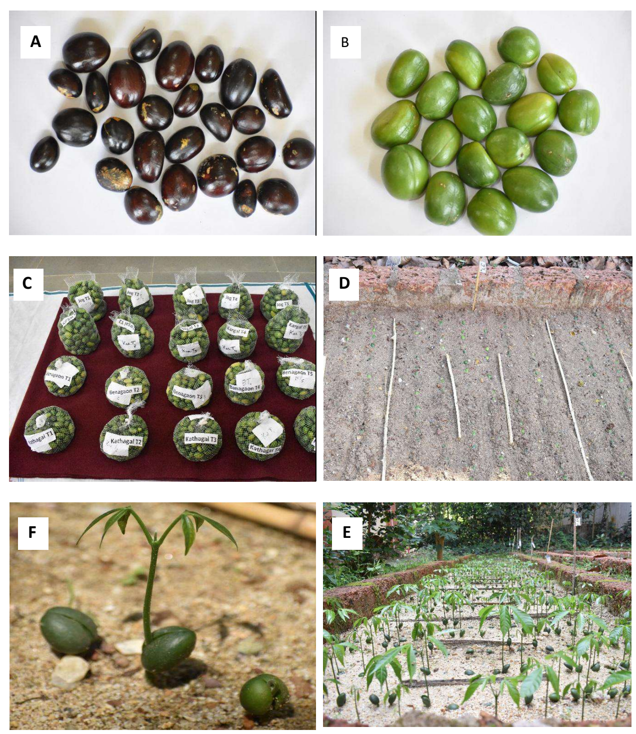

Plate 2. A: Seeds with fatty black seed coat, B: Mature green seeds after removing the seed coat, C: Seeds ready for sowing. D: Sowing of seeds in sand bed, E & F: Pictorial representation of seedlings

different regions, for instance, in the Western Ghats, in the second fortnight of January and in North-East India in the first fortnight of March. The current study found a significant variation in seed germination among seven *D. binectariferum* provenances from four states. Seed germination showed a wide range of variation, ranging from 98.33 to 28.89 percent (Table 2). The seed lot collected from the Western Ghat region (except Lonavala) resulted in significantly higher germination (>74%) than the seed lot collected from the North-East region, namely Manas (72.44%) and Phasighat (57.78%). Among the populations, Jog was superior in germination percent (97.17%), speed of germination (0.76), peak value germination (1.50), germination value (2.13). The highest mean daily germination (1.21), germination rate (19.53) were recorded for Kargal and the least germination traits were recorded by the Lonavala population. The result showed that germination per cent was positively related with altitude (R^2= 0.36), negatively with latitude (R^2 = 0.62) and longitude (R^2 = 0.59). Hence, higher altitudinal and lower longitudinal, latitudinal seed sources performed better germination traits than others. Racial variation among populations of various origins was related to locality factors such as latitude, longitude, and altitude (Jagadish et al 2014). Variations in seed germination traits among natural populations can help with tree selection for domestication. Higher seed weight populations have resulted in higher germination, as confirmed by using families derived from across distribution. As a result, heavier seeds should be preferred to produce higher quality seedlings (Manjunath 2003). The variations could be attributed to the genetic potential of the seed sources and mother trees (Hanumanth 2020). The study suggested that differences in germination traits could be due to wide variations in microclimate and local environmental conditions across the species' range of distribution (Mahajan et al 2015). The genetic constitution of the species for specific traits must have changed as a result of a specific set of local environmental conditions, resulting in geographically distinct clines (Kumara et al 2014). The species' occurrence across a broad geographical range encompassing a wide range of edapo-climatic conditions in its habitat is expected to reflect in the genetic makeup of its diverse populations (Jagadish et al 2014). Similar variations in tropical tree species such as *Dysoxylum malabaricum* (Vasudeva et al 2005) and *Garcinia gummigutta* have also been observed (Bhagyavanth et al 2010).

The germination traits had shown larger variations among the trees of different provenances. JT1 tree from Jog showed maximum germination percent (98.33%) followed by JT2 and JT5 with 97.50%. The maximum germination rate was 21.04 (KaT3) followed by 20.26 (KaT4) and least 2.02 (LT3). KaT5 recorded 0.79 speed of germination. The variation of the peak value of germination ranged from 1.53 (JT1) to 0.20 (LT1) while mean daily germination starts from 1.62 (KaT4) to 0.29 (LT5) and germination value varied from 2.20 (JT5) to 0.05 (LT3) (Table 2). Gunaga et al (2015) observed tree-to-tree variation in seed germination of *Dysoxylum binectariferum*, with seeds collected from ten distant individuals of a single population revealing an overall mean germination per cent (77.4%). The germination percentage of the DB-41 tree was highest (93.7%), while the germination percentage of the DB-02 tree was lowest (64.00%). This variation could be attributed to environmental factors that shaped genetic variation in reproductive traits. The germination study on *Dysoxylum malabaricum* revealed average germination after 12 days, with overall germination ranging from 98 to 100% (Manjunath 2003).

CONCLUSION

The current research reveals that in *Dysoxylum binectariferum*, different regions, provenances, and individual trees within each provenance influenced seed germination. The extent of variation was unearthed to be greater between provenances than between trees. The significant variation could be attributed to the seed source's altitude, longitude, and latitude, which appear to have a direct influence on seed germination. Higher tree to tree variation

Table 1. Passport data of *D. binectariferum* seed sources considered for the investigation

Bioclimatic region	State	Location/Place	Altitude (msl)	Latitude (°)	Longitude (°)
North-East India	Arunachal Pradesh	Phasighat	194	28.06407	95.31755
	Assam	Manas	110	26.64237	90.91727
Western Ghat	Maharashtra	Lonavala	619	18.75083	73.41416
	Karnataka	Jog	583	14.2291	74.8181
		Kargal	491	14.2214	74.8422
		Benagaov	525	14.6021	74.5925
		Kathagal	67	14.4832	74.4807

Table 2. Effect of seed source variation on germination of *Dysoxylum binectariferum*

Source	Trees	Germination (%)	Germination rate	Speed of germination	Mean daily germination	Peak value of germination	Germination value
Joga	JT1	98.33 (84.26)	19.67	0.78	1.22	1.53	2.16
	JT2	97.50 (83.25)	18.35	0.77	0.86	1.51	2.17
	JT3	96.67 (82.82)	18.08	0.77	1.31	1.50	2.05
	JT4	95.83 (78.78)	14.32	0.73	0.87	1.48	2.08
	JT5	97.50 (83.25)	15.44	0.72	0.79	1.50	2.20
	Mean	97.17^{a} (82.47)	17.17	0.76	1.01	1.50	2.13
Kargal	KaT1	90.00 (70.84)	18.50	0.73	0.83	1.43	1.96
	KaT2	90.00 (70.84)	18.23	0.72	1.53	1.43	2.01
	KaT3	93.33 (73.73)	21.04	0.75	1.26	1.46	2.10
	KaT4	95.83 (78.78)	19.63	0.78	1.62	1.47	2.00
	KaT5	95.00 (77.08)	20.26	0.79	0.82	1.46	2.14
	Mean	92.83^{b} (74.25)	19.53	0.75	1.21	1.45	2.04
Benagav	BT1	82.50 (64.67)	16.90	0.63	0.36	1.27	1.99
	BT2	80.00 (64.06)	16.40	0.64	0.87	1.23	2.04
	BT3	81.67 (65.84)	16.58	0.64	0.80	1.23	1.94
	BT4	82.50 (64.67)	14.06	0.63	0.92	1.28	2.25
	BT5	83.33 (65.53)	14.25	0.59	1.02	1.32	1.98
	Mean	82.00^{c} (64.96)	15.64	0.62	0.79	1.26	2.04
Kathagal	KtT1	74.17 (61.00)	12.60	0.65	0.77	1.20	1.94
	KtT2	76.67 (61.62)	11.31	0.61	1.13	1.27	1.91
	KtT3	80.00 (64.06)	10.78	0.61	0.74	1.27	2.01
	KtT4	72.50 (59.57)	15.30	0.61	0.72	1.24	1.73
	KtT5	70.83 (57.53)	11.81	0.62	0.82	1.17	0.49
	Mean	74.83^{d} (60.75)	12.36	0.62	0.84	1.23	1.62
Lonavala	LT1	35.56 (36.57)	3.70	0.10	0.31	0.20	0.06
	LT2	48.89 (44.79)	6.85	0.18	0.36	0.33	0.06
	LT3	28.89 (29.55)	2.02	0.08	0.36	0.22	0.05
	LT4	55.56 (51.25)	7.80	0.24	0.51	0.37	0.09
	LT5	35.56 (36.57)	6.13	0.08	0.29	0.24	0.06
	Mean	40.89^{f} (39.75)	5.30	0.14	0.37	0.27	0.07
Manas	MT1	97.78 (88.34)	17.68	0.48	0.69	0.92	0.29
	MT2	75.56 (61.35)	9.96	0.32	0.53	0.60	0.40
	MT3	64.44 (55.72)	4.44	0.25	0.46	0.45	0.24
	MT4	68.89 (58.58)	5.70	0.30	0.49	0.55	0.19
	MT5	55.56 (51.25)	6.73	0.25	0.41	0.44	0.20
	Mean	72.44^{d} (63.05)	8.90	0.32	0.52	0.59	0.26
Phasighat	PT1	53.33 (49.54)	6.90	0.28	0.51	0.42	0.17
	PT2	53.33 (49.54)	8.90	0.24	0.41	0.44	0.13
	PT3	62.22 (52.67)	7.51	0.28	0.44	0.49	0.18
	PT4	55.56 (51.25)	7.51	0.27	0.41	0.55	0.19
	PT5	64.44 (55.72)	8.52	0.28	0.46	0.51	0.23
	Mean	57.78^{e} (51.74)	7.87	0.27	0.44	0.48	0.18
			CD (p=0.05)	CD (p=0.05)	CD (p=0.05)	CD (p=0.05)	CD (p=0.05)
Sources			4.16	0.12	0.12	0.04	0.07
Trees			3.52	0.10	0.10	0.03	0.06
Sources×Trees			9.30	0.27	0.27	0.09	0.17

* Values in parenthesis are arcsine transferred value

observed for seed germination traits could be due to genetic dissimilarity among the trees, as recalcitrant seeds of the species may be dispersed within a narrow range due to a lack of dormancy. Jog source was superior with respect to germination traits. Therefore, this source may be used for domestication by using superior trees and large-scale plantation programme. Information generated here would be helpful for nursery entrepreneurs and researchers for further tree improvement programme.

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Application of the Caputo Fractional Domain in Stage Structured Predator-Prey Dynamics

Manisha Krishna Naik and Chandrali Baishya
Department of Studies and Research in Mathematics
Tumkur University, Tumkur-572 103, India
E-mail: manishakn06@gmail.com

***Abstract*:** One of the most exciting fields of applied mathematics in recent years has been the study of biological species behavior. The significance of protecting endangered species in nature has led academics from a variety of disciplines to focus on this problem. The development of fractional order derivatives and new ideas in numerical analysis have made it possible for the researchers to save more details about the development of the behaviour of the dynamical systems through time and to use those details for future traits. Sea lions are the prey and sharks are the predators. The prey population is divided into two categories: immature and mature prey. In this model, suppose that the shark (predator) feeds on both mature and immature sea lions, followed by a Crowley–Martin type functional response (CMFR), and that there would be intra-species competition among sea lions as well as sharks. Caputo fractional derivative is used to highlight the link between mature sea lions, juvenile sea lions, and sharks. In this study, we examine the given solution's positivity, boundedness, existence, and uniqueness and shown permanence of the system is highly dependent on the predation rate, conversion rate, death rate and competition rate. Sharks and sea lions are two key components of the marine environment, specifically decided to focus on these two population groups for research. As shark feeds on both adult and juvenile sea lion, they are coupled with predator–prey interaction to produce a complex combined effect as regulators of their population sizes. Caputo fractional derivative is concluded to glean further knowledge about the dynamics of this interaction. The predator feeds not just on mature prey but also on immature prey because they are unable to defend themselves or hide. On prey-predator dynamics, the effect of fractional derivative as well as the influences of various parameters, including the predation rate of mature sea lions, the rate at which mature sea lions turn into sharks, the rate at which immature sea lions die naturally, the rate at which immature sea lions are preyed upon, and the rate at which mature sea lions compete with one another, have been investigated numerically. The number of sea lions and sharks are directly correlated. One of the most significant findings indicate that the predator population is under control, even while the rate of predation is on the rise since not all predators survive for a variety of reasons, including diseases, competition for food, and its own predators. With the aid of a new fractional operator and projected technique, the analysis of the current dynamical system can assist us in comprehending a variety of models in predator-prey ecosystems that are home to fascinating phenomena.

***Keywords*:** Prey-predator model, Mature and immature prey, Predictor-corrector method, Crowley-Martin functional response

Sea lions are marine mammals, characterized by long fore flippers, external ear flaps, short and thick hair, and a big chest and belly. These mammals have ability to walk on all fours. Three species, the Australian sea lion, the Galápagos sea lion and the New Zealand sea lion are listed as endangered. Sea lions are pinnipeds who have three main predators which mainly includes sharks. Many researchers believe that the sea lion can easily swim faster than sharks. However, it is surprise that still these mammals are prey to sharks. The very young (immatured) or those that are sick won't be able to move faster hence they are easily catchable by predators. Sea lions can sense when killer sharks are near by. As every prey has defense mechanism, these mammals also do have such as to get to the edge of the water and onto land. Prey-predator model is used to depict the sea lion-shark dynamics in this work. The predator is the sharks, while the prey are the sea lions. The interaction between predator and prey was initially investigated independently by Lotka and Volterra in order to depict the scenario in real life with relevant assumptions. It has gained a lot more importance and has been widely considered because of its significant part in the ubiquitous presence of mathematical models in ecology, as well as a wide range of applications (Selvam 2020). Ecological modelling aims to produce more accurate mathematical models and better explanations in mathematical language with biological interpretations (Zhang 2022).

The functional response (FR), on the other hand, is a unique and noteworthy component that plays a key role in all predator-prey interactions. When a change in prey density is attached per unit time per predator, it is referred to be a FR (Zhang 2022). Some of the notable functional responses are Holling type I, II, III, and IV FR (Mortoja 2019), Bedington-DeAngelis FR (Beddington 1975, DeAngelis 1975, Jawdat

2023, Liu 2011), Leslie-Gower FR (Wei 2016) and square root FR (Panja 2021). When both prey and predator populations are large, the Crowley Martin functional response (CMFR) is used as a predator interference function. The predator-prey model with CMFR was originally proposed by Crowley and Martin (Martin 1989). The Beddington-Deangelis functional reaction is similar to this functional response. This varies only by one extra term, which describes how predators interfere with one another when prey is densely packed. Meng et al (2014) and Maiti (2019) considered a prey and predator model with CMFR and stage structure for prey, where the authors studied the global stability and persistence of the model. More research related to the CMFR can be found in earlier refrences (Tripathi 2016, Kang et al 2017, Dubey 2018, Ghanbari 2020). Other than the predator-prey dynamics, involvement of CMFR can also be noticed in the works related to Human Immunodeficiency Virus (HIV), viral dynamics models, and other infectious (Kumari 2019, Tripathi et al. 2020, Keeley et al 2021, Pandey et al 2022). Liao (2017) used CMFR to see the delayed dynamics of the phytoplankton-zooplankton system. To perform a non-autonomous stochastic analysis of the prey-predator model (Zhang 2016, Xu 2019), the CMFR is used. Further to analyze bifurcation and chaos control involving two delay times, discrete-time CMFR is used (Liu 2019).

For many scientific societies, studying ecological phenomena has remained a perennially appealing topic. The development of fractional calculus has proven to be a useful tool in this process. Fractional derivatives are trending as one of the most effective and essential tools to the physical systems (Delavari 2012, Prakasha 2019, Veeresha 2019, Gao et al 2020, Baishya 2021a, Achar et al 2022, Abu-Shady 2022, Özköse et al 2022). The objective of this study to develop model that depicts interactions between immature sea lions, mature sea lions, and shark populations, with sea lions acting as prey and shark acting as predator in the frame of the Caputo fractional derivative. In the rest of this paper also discussed positivity, boundedness, conditions of existence and uniqueness, their stability analysis, and several numerical simulations concerning different parameters.

MATERIAL AND METHODS

As Caputo fractional derivatives support the integer-order initial conditions, the fractional derivative in this work is considered in the Caputo sense. Here, d^{α}_{to} denotes the Caputo fractional derivative.

Preliminaries

Definition 1: The fractional order integral operator of Riemann-Liouville is defined as (Podlubny 1998)

$$J_v^{\alpha} f(v) = \frac{1}{\Gamma(\alpha)}\int_0^v \frac{f(t)}{(v-t)^{\alpha-1}}dt, \alpha > 0,$$
$$J^0 f(v) = f(v).$$

Definition 2:*(Caputo Fractional Derivative)* (Podlubny 1998) *The Caputo derivative with fractional order $0 < \alpha < 1$ of function $g(t)$ is defined by:*

$$D_{t_0}^{\alpha} g(t) = \frac{1}{\Gamma(1-\alpha)}\int_0^t (t-\tau)^{-\alpha} g'(\tau)d\tau,$$

where $\Gamma(\cdot)$ refers to Gamma function.

Lemma 1:(Li et al. 2017) *Assume that q(t) is a continuous function on (t0, +) which satisfies*

$$D_{t_0}^{\alpha} q(t) \le -\lambda q(t) + \xi q(t_0) = q_{t_0},$$

here $0 < \alpha \le 1$, $(\lambda,\xi) \in R^2$ and $\lambda \neq 0$ and consider $T_0 \ge 0$ as the initial time. Now,

$$q(t) \le (q(t_0) - \tfrac{\xi}{\lambda})E_{\alpha}[-\lambda(t-t_0)^{\alpha}] + \tfrac{\xi}{\lambda}.$$

Mathematical model formulation: In this paper,a three species stage structured sea lion-shark model is proposed by applying the three species Crowley-Martin functional response model in the frame of Caputo fractional derivative.It includes immature sea lions (Xi), mature sea lions (X_m) and shark (Y).

$$\begin{aligned} D_{t_0}^{\alpha} X_i &= \lambda X_m - (r+\delta)X_i - \zeta_1 Y X_i - \mu X_i^2, \\ D_{t_0}^{\alpha} X_m &= r X_i - k X_m^2 - \frac{\gamma_1 X_m Y}{(1+aX_m)(1+bY)} - \delta_1 X_m, \\ D_{t_0}^{\alpha} Y &= \frac{\gamma_2 X_m Y}{(1+aX_m)(1+bY)} - \delta_2 Y - \beta Y^2 + \zeta_2 Y X_i. \end{aligned} \tag{1}$$

Here, λ is the growth rate of the young population, r is the rate of conversion from immature sea lions to mature sea lions, δ is the natural death rate of immature sea lions, ζ_1 is the rate of interaction between immature sea lions and shark and immature sea lions, μ is intraspecific competition among immature sea lions happens when they have to live in the limited area because of sharks fear. Hence they get limited food which makes to compete even among immature sea lions, k is intraspecific competition among mature sea lions, and γ_1 is the rate of interaction between mature sea lions and sharks. Here, we have assumed that sharks depends on both mature and immature sea lions for food and consumes both. δ_1 is the natural death rate of mature sea lions, and γ_2 is the conversion rate from mature sea lions to shark (as shark survives due to sea lions consumption, shark gives birth to offsprings), δ_2 is the natural death rate of shark, ζ_2 rate of interaction between immature sea lions and shark, β is intraspecific competition among sharks which occurs for food, breeding, etc, a and b are two positive constants that represent the magnitude of interference among sea lions and sharks.

Uniqueness and existence: The existence of the solutions of the proposed model (1) is demonstrated using the fixed-point theorem in this section. Since the model (1) is complex and non-local, there are no accurate approaches for evaluating the exact solutions. Still, existence can be guaranteed if expected conditions are met. The system (1) can be rewritten as:

$$D_{t_0}^{\alpha}[X_i(t)] = \mathbb{A}_1(t, X_i),$$
$$D_{t_0}^{\alpha}[X_m(t)] = \mathbb{A}_2(t, X_m), \quad (2)$$
$$D_{t_0}^{\alpha}[Y(t)] = \mathbb{A}_3(t, Y).$$

The system (1) can be transformed into Volterra type integral equation as:

$$D_t^{\alpha}[X_i(t)]X_i(t) - X_i(t_0) = \frac{1}{\Gamma(\alpha)}\int_{t_0}^{t} \mathbb{A}_1(\tau, X_i(\tau))(t-\tau)^{\alpha-1}d\tau,$$
$$X_m(t) - X_m(t_0) = \frac{1}{\Gamma(\alpha)}\int_{t_0}^{t} \mathbb{A}_2(\tau, X_m(\tau))(t-\tau)^{\alpha-1}d\tau, \quad (3)$$
$$Y(t) - Y(t_0) = \frac{1}{\Gamma(\alpha)}\int_{t_0}^{t} \mathbb{A}_3(\tau, Y(\tau))(t-\tau)^{\alpha-1}d\tau.$$

Theorem 1: *In the region e × [t₀, T], where*

$$\varrho = \quad X_i, X_m, Y \ \in \mathbb{R} : max \ |X_i|, |X_m|, |Y| \ \leq \mathfrak{U} \ ,$$

and T < + ∞, the Lipschitz condition is utilized and contraction occurs by the kernel A if

$0 \leq (r + \delta + (\zeta_1 + 2\mu)\mathfrak{U}) < 1$ is correct.

Proof: We will take two functions X_i and $\bar{X}_i$ as:

$$||\mathbb{A}_1(t, X_i) - \mathbb{A}_1(t, \bar{X}_i)|| = ||\lambda X_m - (r+\delta)X_i - \zeta_1 Y X_i - \mu X_i^2$$
$$-\left(\lambda X_m - (r+\delta)\bar{X}_i - \zeta_1 Y \bar{X}_i - \mu \bar{X}_i^{\,2}\right)||$$
$$\leq ||r + \delta + \zeta_1 Y + \mu(X_i + \bar{X}_i)||||X_i(t) - \bar{X}_i(t)|| \quad (4)$$
$$= (r + \delta + (\zeta_1 + 2\mu)\mathfrak{U})||X_i(t) - \bar{X}_i(t)||.$$

Taking $\theta_1 = (r + \delta + (\zeta_1 + 2\mu)\mathfrak{U})$ which implies,

$$||\mathbb{A}_1(t, X_i) - \mathbb{A}_1(t, \bar{X}_i)|| \leq \theta_1 ||X_i(t) - \bar{X}_i(t)||. \quad (5)$$

Consequently, the Lipschitz condition is satisfied for $\mathbb{A}_1$ and if

$0 \leq (r + \delta + (\zeta_1 + 2\mu)\mathfrak{U}) < 1$, then $\mathbb{A}_1$ follows contraction. Likewise, it can be demonstrated and exemplified in the other circumstances as given below:

$$||\mathbb{A}_2(t, X_m) - \mathbb{A}_2(t, \bar{X}_i)|| \leq \theta_2 ||X_m(t) - \bar{X}_m(t)||,$$
$$||\mathbb{A}_3(t, Y) - \mathbb{A}_3(t, \bar{Y})|| \leq \theta_3 ||Y(t) - \bar{Y}(t)||. \quad (6)$$

Where $\theta_2 = \delta_1 + (2k + \gamma_1)\mathfrak{U}$, $\theta_3 = \delta_2 + \zeta_2(2\beta + \gamma_2)\mathfrak{U}$ are the bounded functions if

$0 < \theta_i < 1$, $i = 2,3$ and then $\mathbb{A}_i$, $i = 2,3$ are the contraction.

Theorem 2: *The solution of the system (1) exists and will be unique, if we acquire some t_α such that*

$\frac{1}{\Gamma(\alpha)}\theta_i t_\alpha < 1$, for i=1,2,3.

Proof: This theorem proof is proved in three parts.

1. Using system (3), it is written with recursive form as follows:

$$\mathfrak{M}_{1,n}(t) = X_{i_{n(t)}} - X_{i_{n-1}(t)}$$
$$= \frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_1(\tau, X_{i_{n-1}(t)})$$
$$- \mathbb{A}_1(\tau, X_{i_{n-2}(t)}))(x-\tau)^{\alpha-1}d\tau,$$
$$\mathfrak{M}_{2,n}(t) = X_{m_{n(t)}} - X_{m_{n-1}(t)}$$
$$= \frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_2(\tau, X_{m_{n-1}(t)})$$
$$- \mathbb{A}_2(\tau, X_{m_{n-2}(t)}))(x-\tau)^{\alpha-1}d\tau,$$
$$\mathfrak{M}_{3,n}(t) = Y_n(t) - Y_{n-1}(t) = \frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_3(\tau, Y_{n-1}) -$$
$$\mathbb{A}_3(\tau, Y_{n-2}))(x-\tau)^{\alpha-1}d\tau. \quad (7)$$

The prerequisities are $X_{i_0}(t) = X_i(0), X_{m_0}(t) = X_m(0), Y_0(t) = Y(0)$. Later applying norm to the equation (7) we get

$$||\mathfrak{M}_{1,n}(t)|| = ||X_{i_n(t)} - X_{i_{n-1}(t)}||$$
$$= ||\frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_1(\tau, X_{i_{n-1}}) - \mathbb{A}_1(\tau, X_{i_{n-2}}))(x-\tau)^{\alpha-1}d\tau||,$$
$$\leq \frac{1}{\Gamma(\alpha)}\int_0^t ||(\mathbb{A}_1(\tau, X_{i_{n-1}}) - \mathbb{A}_1(\tau, X_{i_{n-2}}))(x-\tau)^{\alpha-1}d\tau||. \quad (8)$$

Using Lipschitz condition, (4), we obtain,

$$||\mathfrak{M}_{1,n}(t)|| \leq \frac{1}{\Gamma(\alpha)}\theta_1 \int_0^t ||\mathfrak{M}_{1,n-1}(\tau)d\tau||, \quad (9)$$

Similarly,

$$||\mathfrak{M}_{2,n}(t)|| \leq \frac{1}{\Gamma(\alpha)}\theta_2 \int_0^t ||\mathfrak{M}_{2,n-1}(\tau)d\tau||,$$
$$||\mathfrak{M}_{3,n}(t)|| \leq \frac{1}{\Gamma(\alpha)}\theta_3 \int_0^t ||\mathfrak{M}_{3,n-1}(\tau)d\tau||. \quad (10)$$

As a result, we can write,

$$X_{i_n(t)} = \sum_{i=1}^{n} \mathfrak{M}_{1,i}, X_{m_n(t)} = \sum_{i=1}^{n} \mathfrak{M}_{2,i}, Y_n(t) = \sum_{i=1}^{n} \mathfrak{M}_{3,i},$$

Applying equations (9) and (10) recursively, we obtain,

$$||\mathfrak{M}_{1,n}(t)|| \leq ||X_{i_n(0)}||[\frac{1}{\Gamma(\alpha)}\theta_1 t]^n,$$
$$||\mathfrak{M}_{2,n}(t)|| \leq ||X_{m_n(0)}||[\frac{1}{\Gamma(\alpha)}\theta_2 t]^n,$$
$$||\mathfrak{M}_{3,n}(t)|| \leq ||Y_n(0)||[\frac{1}{\Gamma(\alpha)}\theta_3 t]^n. \quad (11)$$

As a result, the existence and continuity are proved.

2. To illustarte that the relation equation (11), form the solution for equation (1), we make the following assumptions:

$$X_i(t) - X_i(0) = X_{i_n t} - \mathfrak{T}_{1n}(t),$$
$$X_m(t) - X_m(0) = X_{m_n t} - \mathfrak{T}_{2n}(t), \quad (12)$$
$$Y(t) - Y(0) = Y_n t - \mathfrak{T}_{3n}(t).$$

In order to achieve the expected outcome we set,

$$||\mathfrak{T}_{1n}(t)|| = ||\frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_1(\tau, x) - \mathbb{A}_1(\tau, x_{n-1}))d\tau||,$$

This gives,

$$||\mathfrak{T}_{1n}|| \leq \frac{1}{\Gamma(\alpha)}\theta_1 ||x - x_{n-1}||t, \quad (13)$$

Continuing the same procedure recursively, we obtain

$$||\mathfrak{T}_{1n}|| \leq \left(\frac{1}{\Gamma(\alpha)}\theta_1 t\right)^{n+1}\mathfrak{U}, \quad (14)$$

At t_α, we have

$$||\mathfrak{T}_{1n}(t)|| \leq (\frac{1}{\Gamma(\alpha)}\beta_1 t_\alpha)^{n+1}\mathfrak{U}. \quad (15)$$

From equation (15), we can see, as n tends to ∞, $||\mathfrak{T}_{1n}(t)||$ approaches to 0 provided $\frac{1}{\Gamma(\alpha)}$. Similarly, it can be demonstrated that $||\mathfrak{T}_{2n}(t)||, ||\mathfrak{T}_{3n}(t)||$ tends to 0. Hence the proof.

3. Now we will demonstrate the uniqueness for the system of solutions (1). Let us assume that there is a different set of system solutions, say $\hat{X}_i, \hat{X}_m, \hat{Y}$. As a result of the first equation (3),

$$X_i(t) - \hat{X}_i(t) = \frac{1}{\Gamma(\alpha)}\int_0^t (\mathbb{A}_1(t, X_i) - \mathbb{A}_1(t, \hat{X}_i))d\tau,$$

Using the norm, the above equation becomes:

$||X_i(t) - \hat{X}_i(t)|| = \frac{1}{\Gamma(\alpha)}\int_0^t ||(\mathbb{A}_1(t, X_i) - \mathbb{A}_1(t, \hat{X}_i))d\tau||$. (16)

By Lipschitz condition,

$||X_i(t) - \hat{X}_i(t)|| \le \frac{1}{\Gamma(\alpha)}\theta_1 t||X_i - \hat{X}_i||$,

This results is,

$||X_i(t) - \hat{X}_i(t)||(1 - \frac{1}{\Gamma(\alpha)}\theta_1 t_\alpha) \le 0$.

Since $(1 - \frac{1}{\Gamma(\alpha)}\theta_1 t_\alpha) > 0$, we much have $||X_i(t) - \hat{X}_i(t)|| = 0$. This implies $X_i(t) = \hat{X}_i(t)$.

Positivity : In the biological system it is essential to ensure that all the solutions are non negative. Let $\mho_+ = \boldsymbol{X_i, X_m, Y} \in \mho: \boldsymbol{X_i, X_m, Y} \in \mathbb{R}_+$ where $\mathbb{R}_+$ is the set of non-negative real numbers. First let us show that $\boldsymbol{X_i(t)} \ge \boldsymbol{0}$ all t $\in [\boldsymbol{t_0}, \boldsymbol{T}]$. If possible, let us assume that there exist $\boldsymbol{t_2}$ such that $\boldsymbol{X_i(t_2)} < 0, \boldsymbol{X_m(t)} \ge \boldsymbol{0}, \boldsymbol{Y(t)} \ge 0$.

Now $X_i(t_0) > 0, X_i(t_2) < 0$ implies that there exists some $t_1 \in (t_0, T]$ such that $X_i(t_1) = 0$, but $X_m(t_1) \ge 0, Y(t_1) \ge 0$. From the system of first equation (1), it implies that $X_i(t_2) = 0$ which contradicts the assumption that $X_i(t_2) < 0$

Therefore, $X_i(t) \ge 0 \forall \in [t_0, T]$. Similarly, we can show that $X_m(t) \ge 0, Y(t) \ge 0$ $\forall \in [t_0, T]$.

Boundedness : Here determine the solutions of the system ($\mathbf{1}$) are bounded.

Theorem: *The solutions of the system* (1) *are uniformly bounded.*

Proof.- Define a function, $\mathfrak{Y}(t) = X_i(t) + X_m(t) + Y(t)$,by using the lemma (1) we get,

$$
{}_{t_0}^{C}D_t^\alpha \mathfrak{Y}(t) + \delta_1 \mathfrak{Y}(t) = {}_{t_0}^{C}D_t^\alpha [X_i(t) + X_m(t) + Y(t)] + \delta_1[X_i(t) + X_m(t) + Y(t)]
$$

$$
= \lambda X_m - (r+\delta)X_i - \zeta_1 Y X_i - \mu X_i^2 + rX_i - kX_m^2 - \frac{\gamma_1 X_m Y}{(1+aX_m)(1+bY)} - \delta_1 Y + \tag{17}
$$

$$
\frac{\gamma_2 X_m Y}{(1+aX_m)(1+bY)} - \delta_2 Y - \beta Y^2 + \zeta_2 Y X_i + \delta_1(X_i + X_m + Y)
$$

$$
\le \lambda X_m + \zeta_2 Y X_i + \gamma_2 X_m Y + \delta_1(X_i + X_m). \tag{18}
$$

The solution exists and is unique in

$\mho = (X_i, X_m, Y)/max\{|X_i|, |X_m|, |Y|\} \le \mathfrak{P}\}$,

The above inequality yields,

$$
{}_{t_0}^{C}D_t^\alpha \mathfrak{Y}(t) + \delta_1 \mathfrak{Y}(t) \le (\lambda + 2\delta_1 + \zeta_2 \mathfrak{P} + \gamma_2 \mathfrak{P})\mathfrak{P},
$$

By the lemma 1, we get

$$
{}_{t_0}^{C}D_t^\alpha \mathfrak{Y}(t) \le
$$

$$
(\mathfrak{Y}(t_0) - \frac{1}{\delta_1}((\lambda + 2\delta_1 + \zeta_2\mathfrak{P} + \gamma_2\mathfrak{P})\mathfrak{P})E_\alpha[-\eta(t-t_0)^\alpha] +
$$

$$
\frac{1}{\delta_1}((\lambda + 2\delta_1 + \zeta_2\mathfrak{P} + \gamma_2\mathfrak{P})\mathfrak{P}) \to ((\lambda + 2\delta_1 + \zeta_2\mathfrak{P} + \gamma_2\mathfrak{P})\mathfrak{P}),
$$

$t \to \infty$

Therefore, all the solution of the system (1) that initiates in $\mho$ remained bounded in

$$
\Theta = \{(X_i, X_m, Y) \in \mho_+ | \mathfrak{Y}(t) \le ((\lambda + 2\delta_1 + \zeta_2\mathfrak{P} + \gamma_2\mathfrak{P})\mathfrak{P}) + \epsilon, \ \ \epsilon > 0\}.
$$

RESULTS AND DISCUSSION

Here, the points of equilibrium of the system (1) are found.

1. The shark-free equilibrium point $E_1 = (\hat{X}_i, \hat{X}_m, 0)$ exists.

Theorem: *There exists unique positive shark-free equilibrium point* $E_1 = (\hat{X}_i, \hat{X}_m, 0)$

Proof. The component of E_1 can be obtained by solving the following nonlinear system of equations:

$$
\lambda \hat{X}_m - (r+\delta)\hat{X}_i - \mu \hat{X}_i^2 = 0, \tag{19}
$$

$$
r\hat{X}_i - k\hat{X}_m^2 - \delta_1 \hat{X}_m = 0. \tag{20}
$$

From equation (20) we get,

$$
\hat{X}_i = \frac{kX_m^2 + \delta_1 X_m}{r}. \tag{21}
$$

Using equation (21) in equation (19), we get

$$
\lambda X_m = \frac{kX_m^2 + \delta_1 X_m}{r}\left(r + \delta + \mu\left(\frac{kX_m^2 + \delta_1 X_m}{r}\right)\right),
$$

$$
k(X_m + \delta_1) + k\frac{\delta}{r}(X_m + \delta_1) + \mu\frac{k}{r^2}(X_m + \delta_1)(kX_m^2 + \delta_1 X_m) - \lambda = 0,
$$

$$
X_m^3\left(\frac{\mu k^2}{r^2}\right) + X_m^2(\delta_1 + k\delta_1)\left(\frac{\mu k^2}{r^2}\right) + X_m\left(\delta_1^2\left(\frac{\mu k^2}{r^2}\right) + \frac{l\delta}{r} + k\right) - \left(\frac{k\delta\delta_1}{r} + k\delta_1 - \lambda\right) = 0. \tag{22}
$$

Equation (22) have a unique positive root. Hence, the system(1) has unique shark-freeequillibrium point.

2. The coexistence equillibrium point $E_2 = (X_i^*, X_m^*, Y^*)$ exists.

Its component exists by solving the following system of equations:

$$
\lambda X_m^* - (r+\delta)X_i^* - \zeta_1 Y^* X_i^* - \mu X_i^{2^*} = 0, \tag{23}
$$

$$
rX_i^* - kX_m^{2^*} - \frac{\gamma_1 X_m^* Y^*}{(1+aX_m^*)(1+bY^*)} - \delta_1 X_m^* = 0, \tag{24}
$$

$$
\frac{\gamma_2 X_m^* Y^*}{(1+aX_m^*)(1+bY^*)} - \delta_2 Y^* - \beta Y^{2^*} + \zeta_2 Y^* X_i^* = 0.
$$

(25)

From equation (23), we get,

$$
X_m^* = \frac{r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}}{\lambda}, \tag{26}
$$

Using the equation (26) into equation (24) and (25) one gets,

$$
rX_i^* - k\left(\frac{r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}}{\lambda}\right)^2 - \frac{\gamma_1 Y^*}{(1+bY^*)}\frac{r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}}{(\lambda + a(r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}))}
$$

$$
-\delta_1\left(\frac{r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}}{\lambda}\right) = 0, \tag{27}
$$

$$
\frac{\gamma_2 Y^*}{(1+bY^*)}\frac{r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}}{(\lambda + a(r + \delta + \zeta_1 Y^* X_i^* + \mu X_i^{2^*}))} - \delta_2 Y^* - \beta Y^{2^*} + \zeta_2 Y^* X_i^* = 0. \tag{28}
$$

Hence the X_i^* and Y^* values will be calculated from equations (27) and (28) and putting in equation (26), X_m^* can be determined. Traditional procedure of analysing stability of the interior point of equilibrium, leads to complicated steps. Henceforth we analyse it numerically.

Numerical simulation : In this section, the solution profile of the model (1) is studied numerically by using the Adam-Bashforth numerical method (Diethelm 2002).

Average life span of a sea lion and a shark is 20-30 years. We have assumed the natural death rate of sea lions and sharks in the range of 0.03-0.05. Considering the parametr values as $\delta = 0.02, r = 0.15, k = 0.3, \lambda = 20, a = 2.01, \delta_1 = 0.04, \gamma_1 = 1.7, \gamma_2 = 5, \delta_2 = 0.03, \beta = 0.01, b = 1.01,\ \zeta_1 = 1.8, \mu = 0.001,\ \zeta_2 = 0.01,\ X_{m_0} = 0.5, X_{i_0} = 0.5, Y_0 = 0.5$.For these values, the eigenvalues at E_2 are $(-4.12056, -0.0163328 + i0.336792, -0.0163328 - i0.336792)$.Therefore E_2 (interior equillibrium point) is stable which is observable in Figures. The eigen values of E_1 (shark-free equillibrium point) are $(-4.87059, 2.98032, -0.628312)$ and hence is unstable. From figures, one can observe that the paths or trajectories first oscillate and show an asymptotic behavior which become stable spiral to stable focus. It can be noticed that the fractional-order parameter α plays a significant role. As the fractional order parameter α reduces, we notice that the solution curves of the system (1) converges from stable spiral to stable node. Specifically, when the values of α increases, the solutions of the system show oscillatory dynamics. As immature sea lions decreases, the mature sea lions also decreases since the conversion rate from immature sea lions to mature sea lions decreases. Here, we can see the shark population survival rate by consumption of mature and immature sea lions. In Figure 2 and 3 we have shown the effect of interaction of sea lions and shark(γ_1) for different values of α. It is noticed that increase in the predation rate γ_1 leads to the increase in **the oscillating behavior of the solutions.**

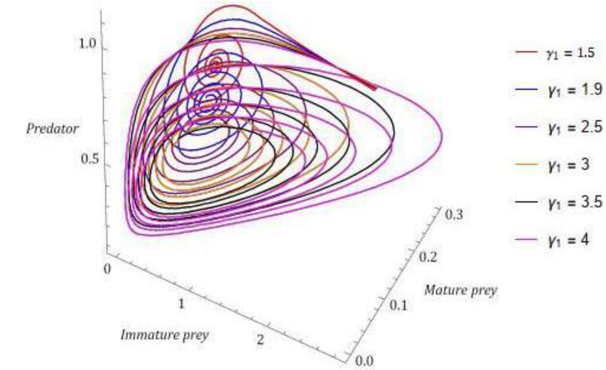

Fig. 2. Effect of predation rate of mature sea lions by shark for α=1

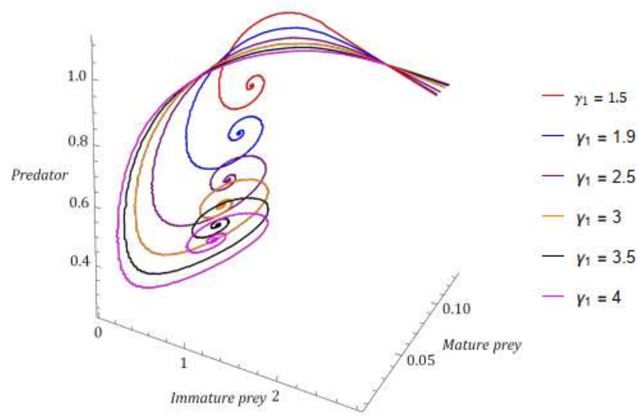

Fig. 3. Effect of predation rate of mature sea lions by shark for α=0.9

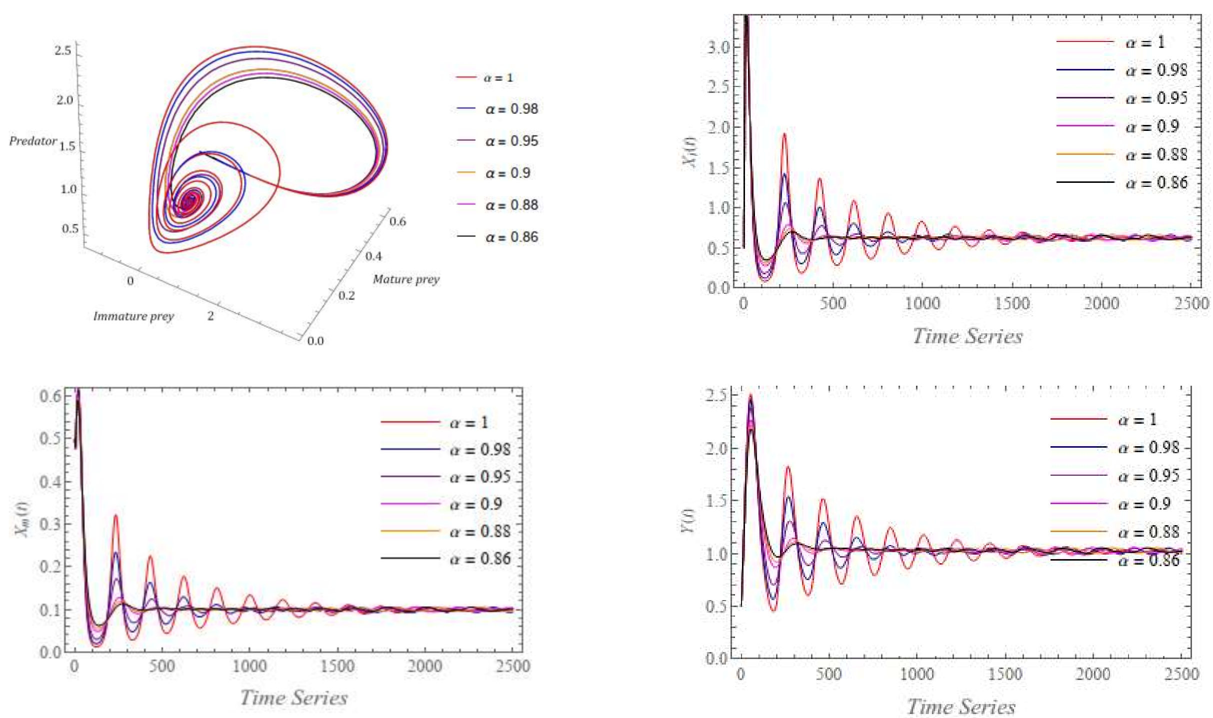

Fig. 1. Numerical simulation for the model with respect to different α

In Figure 4 and 5, we have presented the effect of conversion rate from sea lions to shark (γ_2) for different values of α. It is observed that as the shark population grows extremely, the system observes oscillatory nature.

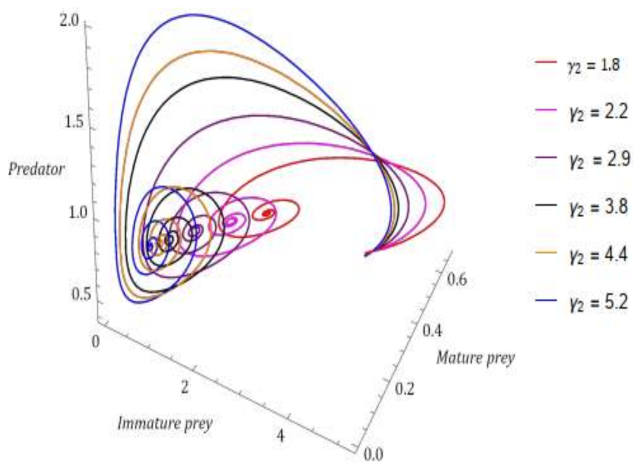

Fig. 4. Effect of conversion rate from mature from mature sea lions to shark for α=0.98

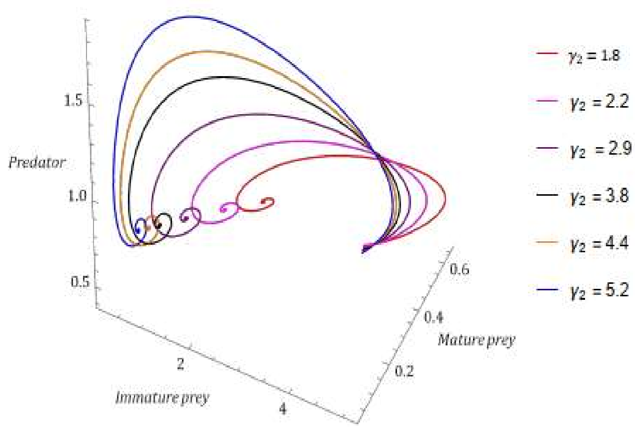

Fig. 5. Effect of conversion rate sea lions to shark for α=0.9

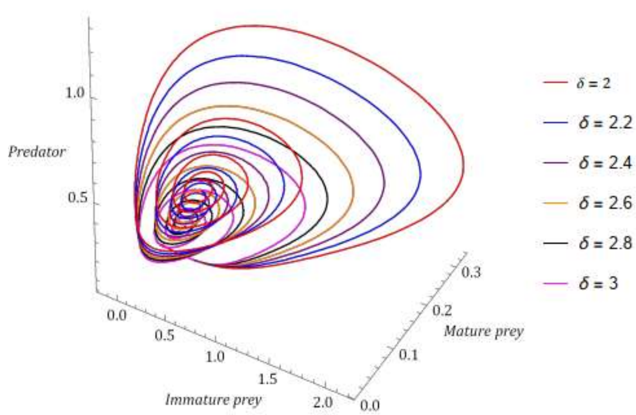

Fig. 6. Effect of natural death rate of immature sea lions at α=1

In Figure 6 and 7, have shown the effect death rate of immature sea lions on all the three populations. Increase in the natural death rate of the immatured sea lions affects the sability of the system. Figure 8 and 9 represent the effect of

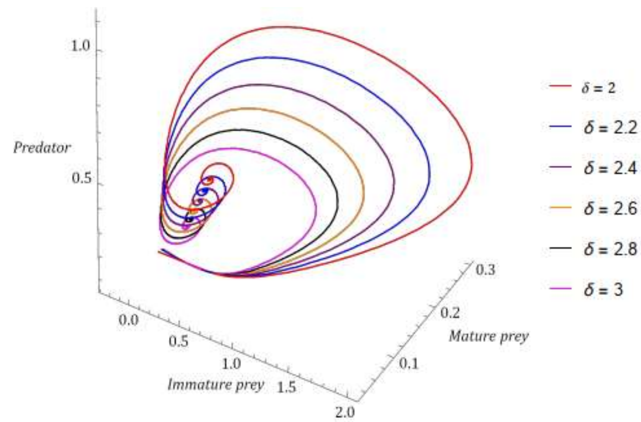

Fig. 7. Effect of natural death rate of immature sea lions at α=0.9

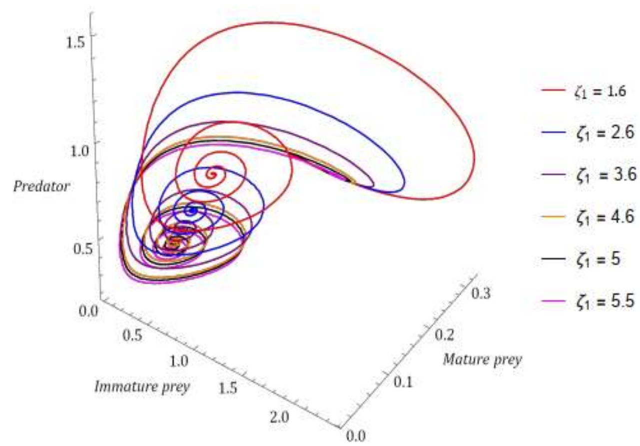

Fig. 8. Effect of predation rate of sea lions by shark at α=0.98

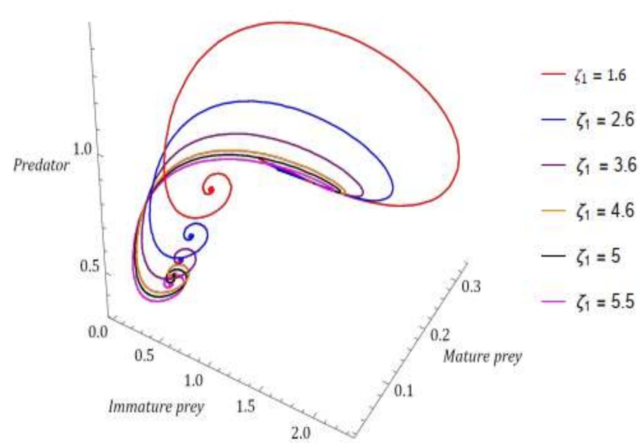

Fig. 9. Effect of predation rate of immature sea lions by shark at α=0.9

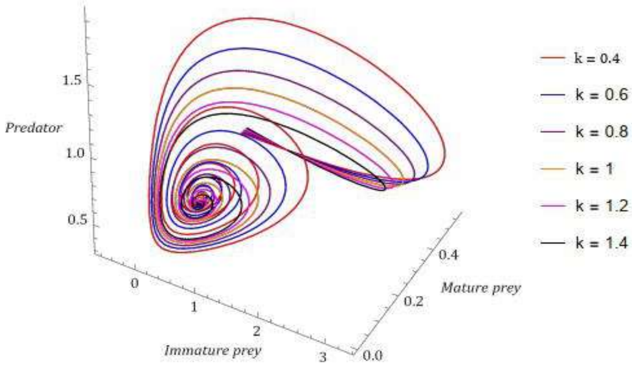

Fig. 10. Effect of competition rate among mature sea lions at α=1

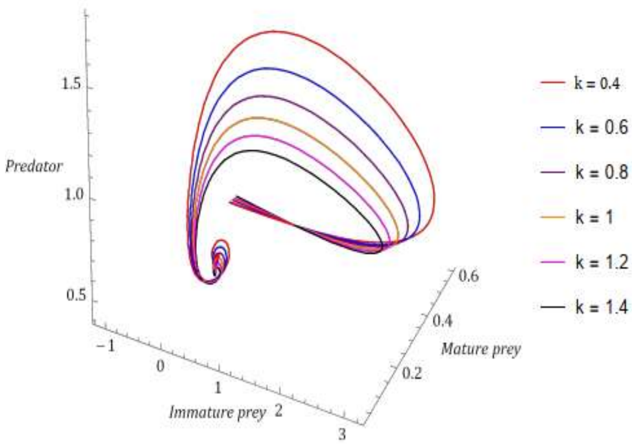

Fig. 11. Effect of competition rate among mature sea lions at α=0.9

interaction among immature sea lions and shark. As immature sea lions have less refuge capacity, sharks attack mostly the immature sea lions. Figure 10 and 11 represent the effect of competition rate among mature sea lions. These figures show that internal competition helps in balancing the populations and fastening the convergence. A common observation made from the numerical simulations is that the presence of fraction derivative influences the stability of the system. It impacts in reducing the oscillatory behaviour of the system.

CONCLUSION

In this paper, a stage structured mathematical model representing the sea lions and shark dynamics has been studied in the framework of Caputo fractional-order derivative. We have used Crowley-Martin functional response to represent the nature of interaction between sea lions and sharks. Important feature of CMFR is that interference effects on feeding rate always remain a prominent factor. A significant point to be noted is that we have introduced competition for food among the immatured sea lions. Also sharks not only hunts mature sea lions, but also hunt immature sea lions. Key findings from the studies incorporated in this paper are that (a) dynamical behaviour of the population not only depends on the values of the parameters but also on the values of the fractional derivative, (b) the permanence of the system is highly dependent on the predation rate, conversion rate, death rate and competition rate, (c) the numerical simulations reveal that the fractional derivative operator has high influence in stabilizing the solution of the system.

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Carbon Storage Potential and Allometric Models for *Acacia catechu* in Forest Land use Systems in Sub-Tropics of Jammu

Vishal Mahajan, N.S. Raina[1], Meenakshi Gupta[1], Pawan Sharma and Punit Choudhary

Krishi Vigyan Kendra Kathua, SKUAST-Jammu-184 101, India
[1]Division of Agroforestry, SKUAST-Jammu-180 009, India
E-mail: vishalmahajan1@gmail.com

Abstract: The study was carried out in *kandi* region of Jammu province to assess carbon storage potential and allometric models for *Acacia catechu* in forest land use systems involving Jammu, Samba and Kathua districts. The vegetation in the study area is represented by Northern dry mixed deciduous forest (5B/C_1), Himalayan sub-tropical pine forest (Type 9/C_1) and sub-type 9/C_{1a} (Lower shivalik chir forest) with *Acacia catechu* as main species among broadleaves. The phytosociology showed that the highest Importance Value Index (IVI) was in *Acacia catechu* (61.62) which shows its pre-dominance in the study area. The total carbon stock from *Acacia catechu* was 4.45 Mg ha^{-1}, out of which 74.15% (3.30 $Mgha^{-1}$) is contributed by aboveground components and 25.85 % (1.15 Mg ha^{-1}) from below ground components. Allometric models were developed for evaluating the best fit equation for aboveground biomass and carbon. The best allometric model for total biomass assessment was (Biomass = $4.152 \times 0.453^{DBH2\times Height}$) on $DBH^2 \times$ Height with adjusted R^2= 0.8026 and AIC = 39.627.

Keywords: Carbon, Biomass, Allometric models, Allometric equations, *Acacia catechu*

Forests play a critical role in global carbon cycle as growing trees remove carbon dioxide from the atmosphere through photosynthesis and have potential to sequester carbon, thus, form an important climate change mitigation option (Kumar and Singh 2003). Theoretically, trees are considered to be the major part of global carbon sink, which involves minimum cost due to natural process of photosynthesis. Consequently, the managed forests can conceptually sequester/ store carbon both *in-situ* (soil and biomes) and *ex-situ* (end products as finished products). The rationale for carbon inventory methods is to estimate emissions or removal of CO_2 from biomass and soil or changes in carbon stocks from a given land-use system resulting from human interventions such as Land-use and land-use changes, felling/ removal of biomass, afforestation, reforestation, forest conservation, burning of above and belowground biomass, soil disturbance leading to reduction in soil organic matter, deep ploughing/tillage and other management practices. Carbon inventory is not directly aimed at climate change mitigation, however, required for activities related to climate change in land-use sector. Forest landuse systems are critical in stabilizing CO_2 concentration in the atmosphere as they offer large mitigation potential besides providing multiple sustainable benefits such as biodiversity conservation, watershed protection, increased crop and grass productivity for stakeholders (Ravindranath and Ostwald 2008).

MATERIAL AND METHODS

Study area: The study was carried out in sub-montane region of the outer Himalayas fringing *Shivalik* hills is popularly known as *bhabar* or *kandi* which stretches between longitude 74° 21' to 75° 45' E and latitude 32° 22' to 32° 55' N covering three districts, namely Jammu, Samba and Kathua. The vegetation in study area was classified into various forest types as per the classification made by Champion and Seth (1968). Northern dry mixed deciduous forest (5B/C_1) is major forest type of the study area with *Acacia catechu, Dalbergia sisoo, Grewia optiva, Dendrocalamus strictus, Acacia modesta, Mallotus philippensis*, *Bombax ceiba, Carissa spinarum, Dodonea viscosa* etc. being the main species. The fringe zone of *kandi* towards its higher reaches comprise of Himalayan sub-tropical pine forest (Type 9/C_1) sub-type 9/C_{1a} (Lower shivalik chir forest). The general floristic composition in the study area of this sub-type includes *Pinus roxburghii*, *Acacia catechu, Dalbergia sissoo, Butea monosperma, Mallotus philippensis, Zizyphus jujuba, Syzygium cumini, Ficus glomerata,* etc. *Acacia catechu* being the one of the main species was selected to assess the carbon storage potential and prediction of biomass models. For selection of random sample points in forest land-use system, the Conservator of Forests (East Circle), Jammu was consulted and the sample points were randomly selected on topographic maps (topo-sheets) after discussions held with Divisional Forest Officers of Jammu and Kathua forest division. In all, 15 sample points were selected in study area comprising three districts viz., Jammu, Samba and Kathua. Global Positioning System (GPS) was used during the field survey exercise to locate the geo-coordinates and altitude of sampling points.

Phytosociology of *Acacia catechu* under forest land use system was calculated. The relative dominance, relative density, relative frequency and importance value index (IVI) were computed. The aboveground standing biomass comprising of all woody stems, branches, leaves of the living trees (deadwood not accounted as the same is removed from the system as fuel), was calculated for marked *Acacia catechu* trees in selected sample point. Non-destructive method was used, which is more rapid and much larger area and number of trees can be sampled, reducing the sampling error encountered with the destructive method (Hairiah et al 2011).

The quadrat size of 10 m x 10 m (0.01 ha) was used in estimation of biomass. All the living trees with stem size >3 cm were measured for estimating the volume of growing stock. The non-destructive measurements of stem diameters were used and allometric equations on the basis of DBH and height were applied. Trees were reckoned and their diameter at breast height (DBH) and height were measured. The stem volume of trees was calculated by using basal area (BA), height and form factor. For standing trees, general form factor of 0.5 was taken regardless of taper or form (Butterfield and Espinoza 1995). The stem volume of *Acacia catechu* was converted into biomass by using wood density (Mg m^{-3}) which was taken as 0.88 Mg m^{-3} (Brown 1997). Irrespective of size and length, the total number of branches were counted on each of the sample tree and were categorized into three parts *viz*., lower, middle and upper. Fresh weight of one sampled branch from each group was recorded separately. The dry weight of branches was determined by as suggested by Chidumaya (1990). The fresh leaves segregated from the harvested branch were weighed and a representative sample thereof (0.1 kg) was retained to estimate the dry weight of leaves. Leaves were oven dried to obtain the constant weight. The below ground biomass of trees was calculated by using the ratio of below-ground to above-ground biomass (Mokany *et al* 2006). Carbon concentration in plants was calculated (Negi et al 2003).

Carbon (%) = 100 – (Ash weight+ molecular weight of O_2 (53.3) in $C_6H_{12}O_6$)

Oven dried plant components (leaves, bark and wood) were burnt in electric furnace at 400°C temperature, ash content (inorganic elements in the form of oxides) left after burning was weighed and carbon was calculated. This carbon concentration was converted in to carbon stock (Mg ha^{-1}) by multiplying it with the biomass. The proportion of stem wood used as long-lived wood products was estimated (Wang and Feng 1995).

The estimated carbon stock was converted into CO_2 equivalent by multiplying the carbon stock of 3.67 (Van Kooten 2004) for calculating CO_2 assimilation by biomass.

Long-lived carbon storage = carbon mass in stem wood 42% stem wood put for long term locking

Heat from biomass combustion and carbon storage from coal substitution (Mg ha^{-1}) was simulated on the basis of thermal efficiency of biomass (Wang and Feng 1995).

Heat from biomass combustion = [Biomass – (stem wood weight 0.42)] 18 10^9 J ton^{-1}

$$\text{Carbon storage from coal substitution} = \frac{(\text{Heat of biomass combustion} \times 0.60 \times 0.70)}{(18 \times 10^9)}$$

The estimated carbon stock was converted into CO_2 equivalent by multiplying the carbon stock of 3.67 (Van Kooten 2004) for calculating CO_2 assimilation by biomass.

Allometric models /equations for the estimating aboveground biomass and carbon were developed and applied on the inventoried data based on direct measurements. Diameter at breast height (DBH) and height were taken as independent variables. The data obtained were subjected to statistical analysis by using SPSS-16, GRETL and OPSTAT.

RESULTS AND DISCUSSION

Phytosociology of *Acacia catechu* and associated trees under forest land use system: The various forest types in the study area were 5B/C_2-Northern dry mixed deciduous forest, 5B/DS_1-Dry deciduous scrub, 5B/E_9-Dry bamboo brakes, 5B/1S_2-Khair-sissoo forest and 9C_1/1a-Lower or shiwalik chir pine (Ashutosh et al 2010).

The maximum relative frequency was in *Acacia catechu* (13.51), followed by *Butea monosperma*, *Cassia fistula, Leucaena leucocephala* and *Mallotus philippensis*. The minimum values (2.70) were exhibited by *Albizia lebbeck*, *Eucalyptus*, *Ficus palmata* and *Prosopis juliflora*. The highest Importance Value Index (IVI) was in *Acacia catechu* (61.62), followed by *A. modesta* (32.94) and *Pinus roxburghii* (31.92). Sharma and Raina (2018) also reported predominance of tree species like *Pinus roxburghii, Acacia modesta, Mallotus philippensis, Dalbergia sissoo* in foot hills of shivaliks. However, in *Pinus roxburghii* the per cent frequency is lower (13.33). This is mainly due to distribution of *Pinus roxburghii* in very constricted patches which are exposed to southern aspect. The findings are also in agreement with the findings of Jhangir (2004). The average diameter and height of 0.11 m and 3.89 m, respectively was recorded in *Acacia catechu* across the forest landuse system (N=51). The average volume of 4.37 m^3 ha^{-1} was with average basal area of 1.18 m^2 ha^{-1}. The average total biomass (17.55 Mg ha^{-1}) with 13.71 Mg ha^{-1} as aboveground biomass and 3.84 Mg ha^{-1} as belowground biomass was recorded. The biomass of a tree and correspondingly its carbon stock depends greatly on its diameter, structure, age, density and intensity of canopy management. Tree growth attributes are decisive components of biomass productivity and hence the carbon content (Newaj et al 2007). The total carbon stock from *Acacia catechu* was 4.45 Mg ha^{-1}, out of which 74.15% (3.30 Mg ha^{-1}) is contributed by aboveground components and 25.85 % (1.15 Mg ha^{-1}) from below ground components. Biomass pattern clearly reflects that the more carbon is allocated to aboveground components than belowground components. These results are in conformity with the results obtained earlier by Mahajan et al (2018), Jha (2005), Chauhan et al (2009) and Pal et al (2009). The long lived carbon storage of 0.70 Mg ha^{-1} was in *Acacia catechu* with CO_2e of 16.32 Mg ha^{-1}. Similar results were reported by Mahajan et al (2021) for trees in agriculture land-use system. Yadav (2010) and Kanime et al (2013) emphasized on estimating the end use of wood for assessing the carbon sequestration potential.

Allometric models for *Acacia catechu* were developed for evaluating the best fit equation for aboveground biomass and carbon. Here, the DBH and height were taken as independent variables. Two equations were framed for assessing aboveground biomass based on DBH× Height, DBH^2 × Height, respectively. The best allometric model for total biomass assessment was (Biomass = 4.152 × $0.453^{DBH2 \times Height}$) on DBH^2 × Height with adjusted R^2 = 0.8026 and AIC = 39.627. Also, five allometric equations were developed for carbon assessment based on total biomass, DBH, height, DBH× Height, DBH^2 × Height, respectively. The best fit equation for carbon assessment was CS = −1.235 × $0.937^{TotalBiomass}$ on the basis of total biomass with adjusted R^2 = 0.8819 and AIC = 14.67. On the basis of independent variables of DBH and height, the best fit equation was for DBH x Height (CS = 2.019 × $0.769^{DBH \times Height}$) with adjusted R^2 =0.845 and AIC = 27.71. It was followed by equation based on DBH^2 × Height (CS = 2.775 × $0.458^{DBH2 \times Height}$) with adjusted R^2=0.825 and AIC = 23.317. The selected models are tested for accuracy based on measured data. The best model should have higher R^2-adj and correlation and AIC than other developed equations. The coefficients for all selected models are statistically significant, which showed strong correlation of AGB with dendrometric variables. The choice of allometric equations has a significant effect on the biomass calculations since the forest biomass estimates vary with age of the forest,

Table 1. Overview of the method used

Parameter	Quadrat size	Method
Living tree with stem size > 3cm	10 m x 10 m (0.01 ha)	Non-destructive measurement of stem diameters; Allometric equations on the basis of DBH and height were applied

Table 2. Relative dominance, relative density, relative frequency and importance value index (IVI) of *Acacia catechu* and associated tree species

Species	Per cent frequency	Abundance	Density	Relative dominance	Relative density	Relative frequency	IVI
Acacia catechu	33.33	9.60	3.20	16.53	31.58	13.51	61.62
Acacia modesta	20.00	6.33	1.27	12.34	12.50	8.11	32.94
Albizia lebbeck	6.67	3.00	0.20	1.20	1.97	2.70	5.87
Butea monosperma	26.67	2.25	0.60	8.40	5.92	10.81	25.13
Cassia fistula	26.67	1.25	0.33	1.45	3.29	10.81	15.55
Dalbergia sissoo	20.00	4.33	0.87	3.48	8.55	8.11	20.14
Eucalyptus sp.	6.67	5.00	0.33	8.83	3.29	2.70	14.82
Ficus palmate	6.67	3.00	0.20	0.51	1.97	2.70	5.19
Flacourtia indica	13.33	1.50	0.20	1.09	1.97	5.41	8.47
Lannea coromendalica	13.33	7.00	0.93	2.35	9.21	5.41	16.97
Leucaena leucocephala	26.67	3.25	0.87	9.00	8.55	10.81	28.37
Mallotus philippensis	26.67	1.75	0.47	3.73	4.61	10.81	19.14
Pinus roxburghii	13.33	2.50	0.33	23.23	3.29	5.41	31.92
Prosopis juliflora	6.67	6.00	0.40	4.87	3.95	2.70	11.52

Table 3. Allometeric models for *Acacia catechu*

Model	Dependent variable	Independent variable	Allometric equation	Estimated coefficients	F-value	Solved equation	R^2 Adjusted & AIC values
Model 1	Biomass	DBH × Height	$Biomass = \alpha \times \beta^{DBH \times Height}$	$\alpha = 3.391^{***}$ $\beta = 0.74^{***}$	184.55^{***}	$Biomass = 3.391 \times 0.749^{DBH*Height}$	$R^2 = 0.796$ AIC = 41.181
Model 2	Biomass	DBH^2 × Height	$Biomass = \alpha \times \beta^{DBH2 \times Height}$	$\alpha = 4.152^{***}$ $\beta = 0.453^{***}$	13.14^{***}	$Biomass = 4.152 \times 0.453^{DBH2 \times Height}$	$R^2 = 0.8026$ AIC = 39.627
Model 3	Carbon	Total Biomass	$CS = \alpha \times \beta^{Total\ Biomass}$	$\alpha = -1.23^{***}$ $\beta = 0.937^{***}$	659.12^{***}	$CS = -1.235 \times 0.937^{TotalBiomass}$	$R^2 = 0.8819$ AIC = 14.67
Model 4	Carbon	DBH	$CS = \alpha \times \beta^{DBH}$	$\alpha = 3.724^{***}$ $\beta = 1.0665^{***}$	140.57^{***}	$CS = 3.724 \times 1.0665^{DBH}$	$R^2 = 0.748$ AIC = 51.062
Model 5	Carbon	Height	$CS = \alpha \times \beta^{Height}$	$\alpha = -0.91^{***}$ $\beta = 1.609^{***}$	26.457^{***}	$CS = -0.914 \times 1.609^{Height}$	$R^2 = 0.630$ AIC = 69.483
Model 6	Carbon	DBH × Height	$CS = \alpha \times \beta^{DBH \times Height}$	$\alpha = 2.019^{***}$ $\beta = 0.769^{***}$	45.198^{***}	$CS = 2.019 \times 0.769^{DBH \times Height}$	$R^2 = 0.845$ AIC = 27.71
Model 7	Carbon	DBH^2 × Height	$CS = \alpha \times \beta^{DBH2 \times Height}$	$\alpha = 2.775^{***}$ $\beta = 0.458^{***}$	224.02^{***}	$CS = 2.775 \times 0.458^{DBH2 \times Height}$	$R^2 = 0.825$ AIC = 23.317

****Significant at 1% level

site class, and stand density. Similar results have been reported by Abola et al (2005), Basuki et al (2009), Kebede et al (2018) and Nam et al (2016).

CONCLUSION

The IVI was measured as the sum of relative density, relative frequency and relative dominance. The highest IVI was found in *Acacia catechu* followed by *Acacia modesta.* Allometric models for estimating the aboveground biomass and carbon were developed based on direct measurements. Diameter at breast height (DBH) and height were taken as independent variables. Based on R^2 adjusted R and akaike information criterion (AIC), models were estimated for *Acacia catechu* due to its pre-dominance in the study area. The best-fit regression model for aboveground biomass and carbon were based on combinations of diameter at breast height (DBH), and height as independent variables. These variables are easy to measure accurately in the field.

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Insect Annihilation: Causes for Decline and Strategic Conservation Plan in 21st Century

R. Pungavi and T. Nalini

Department of Entomology, Faculty of Agriculture
Annamalai University, Chidambaram-608 002, India
E-mail: r.pungavientomology@gmail.com

Abstract: Insects are “six-legged companions”, whereas annihilation is a collective term “event involving in sudden decline or damage on the catastrophic scale due to *Anthropocene*. The decline that may lead to the extinction of 40 percent of the global insect species over the next few decades. pollinators, bees, wasps, beetle populations, terrestrial taxa, and aquatic insects including dragonfly, damselfly, stonefies, mayfly, and caddisfly have lost a substantial proportion of species in the last decades. The main drivers of species declines are change in climate at global leval, intensive agriculture, urbanization, pollution, loss of habitat and biological factors etc. Time is too short for conserving the necessary insect diversity to sustain us. There are six interrelated themes for conservation methods to ensure that insects survive into the twenty-first century and beyond.

Keywords: Arthropods dereases, Climate change, Pollution, Biological factors, Conservation

Insects are referred to as "six-legged companions" whereas annihilation is defined as a "castrotrophic scale event caused by the Anthropocene." According to scientific studies, insect populations have been falling internationally for decades (Wagner et al 2021). Regulations and public concern regarding insect loss have been scarce and mainly neglected since the dawn of civilization. There are approximately 5.5 million insect species in the globe, with 90 percent of these species undiscovered and their biological purpose unknown. Decling of insect species is a major problem due to their ampleness, diversification and extinction of an entire species richness. The word "population decline" refers to both a decrease in insect numbers and a reduction in geographic distribution, which is the first step toward extinction (Sanchezbayo and Wyckhuys 2019). The causes and patterns of insect decline differ according on the region's biotic, abiotic, and anthropogenic factors. The causes are debatable, although they almost certainly include habitat loss, pesticide exposure, pollution, climate change, biological factors, and technology interventions as primary drivers of arthropod decrease (Samways et al 2020). The effects are clear: insects are a vital element of the food chain, providing food for a variety of lower and higher organisms while also aiding in biological pest control, act as pollinator and nutrient recycling. The terrestrial and freshwater ecosystems would collapse without this tiny creatues. The current review is organised into several subsections that describe the timeline of mass extinction events on Earth, followed by the current scenario of insect decrease, primary drivers of insect decline, and conservation activity toward the arthropod community to save little creatures from extinction.

Services to ecology and economy: Insects serve an important part in maintaining environmental equilibrium. They are necessary for the survival of the ecosystem. They recycle the nutrients, pollinate the plants, dispersal of seeds, maintain the soil structure and fertility, manage some other organism populations and serve as a primary food source in the food chain. Insects pollinate over 80% of the blooming plants on Earth (Noriega et al 2018). The pollinators include solitary bees, squash bees, honey bees, bumble bees, beetles, flies and butterflies. Many of the birds, reptiles, bats, tiny mammals, amphibians and fish would become extinct if insects did not exist. About 87 percent of all plant species require animal pollination, with insects providing the majority of it (Ollerton et al 2011). Insects improve the soil structure and make it fertile by decomposition and consuming dung. The dung beetles feed partly or exclusively on dungs or faeces and protect the livestock by removing dungs, if not done it may facilitate a habitat for flies. In many countries, this beetle was introduced the for the goodness of animal husbandry. Insects are an important part of the food chain and predator such as lacewings, ladybird beetles and parasite wasps should helps to control other arthropods and vertebrates. The *Neuroptera* larvae of insects like lacewings owlflies, antlions, mantidflies, snakeflies, spongeflies and dobsonflies that help as predator for controlling insect pests like aphids, leaf hoppers, mites, scale insects, beetles and caterpillars as successful biological control ever. Insects are economically important because they provide honey, shellac, wax, silk and other products. Edible insect species about 1500 were consumed and 3000 by indigenious pepole in 113 countries globally. Grasshoppers, ants beetles, cicadas, bugs, and caterpillars are protein rich nutrient consumed by large number of people. So, insects are the indicators of the healthy ecosystem.

Big five mass extinction have shaped the earth: Among the many unexplained events and mysterious that have occurred on earth over the millions of years. The rapid loss of biodiversity is called as Mass extinction. These events have left earth open to evolutionary changes as new species emerge to replace those that have died. At least five different mass extinctions, known as the Big 5, have been discovered.throughout history about lost 50 to 75% of life was lost. (Gemmatarlach 2018) (Table 1).

Extinction today and current estimates of decline globally*:* Earth is currently experiencing a biodiversity crisis. According to the study, more than 40 percent of arthropod species get lost and one-third are in endangerous line. The extinction rate was eight times that of mammals, birds, and reptiles. Based on the available data, estimated number of insects is decreasing at 2.5 percent per year. This data indicate that they may become extinct within a century. Since we are in 20^{th} century, there has been an increase in Holocene extinction of species, with 95 per cent decline due to Anthropocene. ZSL - Zoological Society of London (2012) reported that vertebrates that is the stating point of insect species decline and 20% of all invertebrates are in grave riskier of extinction globally, with both direct and indirect consequences. Some research found a huge gap of data exist between 1840 and future predictions. due to the global concern about species extinction, the German Nature Reserve gained a lot of attention in 2017 and obtained 27-year long population monitoring study revealed a shocking prediction about 76% decline in flying insect biomass at several of parts Germany's protected areas of global concern about species extinction (Hallmann et al 2017). This equates to 2.8 percent insect biomass loss per year on average . Sadly, the study reveals a consistent downward trend over the three decades. A recent study in Puerto Rican rainforests discovered biomass losses of 98 to 78% for soil dewellling and canopy-dwelling arthropods over a 36-year period, with annual losses of 2.7 to 2.2% (Lister and Garcia 2018). The latter its was reported by many researchers, there was a parallel decline in birds, frogs and lizards which in turn results of food shortages for invertebrate. Those reports were agreeed with the decreasing pattern for aerial flying population (includes house flies, mosquiotes, etc.) observed in earlier parts of Southern Britain. The IUCN Red List, for example, includes only 8400 species on that one million described and 0.2 percent of all extant species. However, that the insect extinctions have been around 5 to 10% since the industrial era, ranged from 2,50,000 to 5,00,000 species (Regnier et al 2015). At least one million species, half of which are insects, are on the verge of extinction in the next ten years (Diaz 2019). Inspite of this 15,000 scientists were signed and humans are factor for "pushing natures tiny beauty beyond their capacity to support the web of life. "Group of entomologists and ecologist worrying about the global vanish of arthropod groups, discussed about insect extinctions, their causes, and the impact they have on

Table 1. Mass extinction events and species lost

Extinction events (Million years ago)	Size of the extinction and species lost	Suspected causes
Ordovician-Silurian extinction-Paleozoic Era (440 MYA*)*	• 85% of all living species eliminated • Marine genera- trilobites, shelled brachiopods, eel-like conodonts, graptolites were died off	Climate change, glaciation and continental drift. Among the major extinction this alone linked with global cooling.
Late Devonian extinction - Paleozoic Era (375MYA)	• 80% of all living species lost • Vascular plants, such as trees and flowers genera were gone extinct.	Volcanic eruptions, quick cooling of air temperatures, lack of oxygen in the oceans.
Permian Mass Extinctions - Paleozoic Era (250 MYA)	• 96% of all living species eliminated • 95 % marine species and 70% land-dwelling vertebrates	Massive volcanic eruptions, Climate change (Carbon dioxide - Bacteria - Methane) Well known largest extinction of insects
Triassic-Jurassic Extinction- Triassic Period of Mesozoic Era (200 MYA)	• More than half of all living species eliminated • Marine and large amphibians related to crocodiles and dinosaur's species got vanished	Reason behind this extinction about volcanic activity with basalt flooding, changing in pH and sea levels at oceans and climate change over longer period,
K-T Mass Extinctions Cretaceous Period of the Mesozoic Era (65 MYA)	• 75% of all living species eliminated • Extinction of mammals, birds, amphibians, reptiles, and insects. Marine reptiles like mosasaurs, plesiosaurs and ammonites were badly affected	Extreme asteroid or meteor impact

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humans. We conclude with a call for instant measures to address our knowledge gaps and prevent insect extinctions.

Are we next?: The question of whether or not the earth is on the verge of another mass extinction has sparked heated debate among scientists. This time, however, neither natural calamities nor valconic reuptions are to blame. Anthropocene were causing a global climate change have accelerated the vanishing of species by ten to one hundred times faster than expected. The scientific proofs were precise: people have been approaching the sixth mass extinction as a result of the Anthropocene "age of humans," in which human activity has impacted climate and environmental trends, leading to insect decline and, as a result, driving us, *Homo sapiens*, down the path to extinction (Cardoso et al 2020)

Drivers of the Declines

Habitat change: Habitat change is the primary cause of insect declines, accounting for 49.7% of all insect declines and having an equal impact on global bird and mammal declines (Chamberlain and Fuller 2000). Pollution (25.8%) followed by biological factors (17.6%), and next to that is climate change (6.9%) are the next most common causes of loss.

Agriculture intensification: Changes in agriculture intensification, deforestation, urbanisation, mining, industrialization, and extractive land uses all contribute to habitat change in the local environmental conditions in which a particular organism lives, which is the greatest current threat to global biodiversity. With agricultural transformation and expansion (24%), urbanisation (11 %), deforestation (9 %), and others (5 %), landscape fragmentation is undoubtedly the leading cause of species diminish (Sanchezbayo and Wyckhuys 2019, Mittermeier et al (2004) found that 50 percent of endemic plant and vertebrate species are restricted to 36 biodiversity hotspots covering only 2.5 percent of the planet, and these hotspots are likely to cover similar percentages of endemic insect diversity (Stork and Habel 2014). Green revolution often leads to larger in extent involved in use of monoculture, high yielding varieties, high use of pesticides and fertilisers, growing of GMO crops that produce insect toxins are all factors that contribute to insect decline. Specialist pollinators like many of bumblebees and wild bees to land-use changes involving loss of floral resources, nesting and hibernation sites known to be a threat factor to bee's decline (Williams and Osborne 2009). For specialist predators like ground beetles, improved irrigation facilities, loss of hedgerows and trees are trigger towards decline of this species (Brooks et al 2012). Agricultural conservation causes stream channelization, wetlands drainage, floodplain modification, and riparian canopy removal, all of which result in soil and nutrient loss, homogenising stream microhabitats and altering aquatic insect communities (Houghton and Holzenthal 2010). Eutrophication resulting in a decrease in diversity of insect such as dragonflies and damselflies aquatic ecosystem for their naiads development. Odonata makes up 106 of the 118 aquatic insect species are in endangered list given by the IUCN (Sahlen et al 2010).

Intensive agriculture involves widespread use of pesticides for controlling crop pests (13 % insecticides), use of fertilizers (10%), killing weeds (herbicides) and diseases (fungicides) (Dudley and Alexander 2017). Most taxa suffered are moth, pollinators, ground dwellers, foliage feeders, lady birds, butterflies, aquatic life., etc. The loss of flying insects like butterfly, dragonfly, etc., and pollinator communities were directly linked to aerial pesticide application. Pesticide use is one of the primary causes of insect decline. This 2nd Silent Spring where neonics are similar to a new DDT, but they are a thousand times more toxic to bees. Neonic pesticides are a major cause of the 'insect decline,' with a 40% loss due to widespread use of this compound. Because of the widespread use of neonicotinoid pesticides, Honeybees are now more toxic (48 times) in America's farming than in last five years. Meta analysis on 17 widespread and resident species of butterflies between 1984 and 2012 showed that abundance of all species decreased by 58% since from 2000, while 15 species exhibited population declines high proportions of farmland treated with neonicotinoid insecticides at average annual rates between −0.8% and −6.7% (Gilburn et al 2015). Insecticides such as neonicotinoids and fipronil both impair the reproductive performance of queens and drones, jeopardising the long-term viability of entire colonies. Merging of chromium and neonicotinoids are more toxic to bees, and the metal had an antagonistic effect on fungicide toxicity (Kairo et al 2017, Sgolastra et al 2018). Neonics are not only extremely toxic to honeybees, but they can also persist in the environment for over 1,000 days. Plants absorbed systemic insecticide during foliar as well as soil application, those toxins were incorporated into leaves, stems, pollen, nectar, sap, etc. Pollen and nectar translocation have an impact on bees, butterflies, hoverflies, and wasps (Vandersluijs et al 2015). Because of their high acute and chronic toxicity, pyrethroid, neonicotinoid, and fipronil insecticides have a devastating impact on aquatic insects and crustaceans, as well as reducing the development of chironomids and other insect larvae, with negative cascading effects on fish survival (Weston et al 2015, Kasai et al 2016). Impair larval viability, undermine the insect food web, natural biological control mechanisms happenings in the ecosystem, and persistent residues in sediments inhibit emergence and do not allow aquatic nymph recovery, contributing to the decline (Jinguji et al 2013). Dragonflies, trichoptera, and ephemeroptera have also been harmed by surface water eutrophication caused by excessive fertiliser use in rural areas. The treatment of livestock with persistent avermectins and insect growth regulators has contributed to a reduction of dung beetles in most of the countries, as residues of these pesticides in dung pats eliminate the developing larvae. Unfortunately, more tolerant species of Ceratopogonidae and Psychodidae flies that breed in the same pats had their numbers boosted in Japan (Iwasa et al 2005). Combination of Azole fungicide and lambda cyhalothrin leads to Collapse to honey bees (Simondelso et al 2014).

Genetically modified organisam (GMO) crops are those that use of any plants, animlas other microorganisams where its DNA modified, have been incroprated modified new trait from one organisam into other. Usage of this GMO crops buildup insecticide and insect resistance to pests and diseases. But growing of GMO crops serious threates for fall off insect population. Massive use of glyphosate (Round up), the toxic weed killer widely sprayed on GMO crops. The widespread use of glyphosate has decimated the milkweed plants on which monarch butterflies lay their eggs (Belsky and Joshi 2018). According to the study, the dwindling monarch population is due to reduction in breeding habitat, particularly in the United States. Between 1999 and 2014, milkweed declined by 40%, while potential monarch host capacity fell by 71%. It concludes that monarch butterflies in the United States may become extinct within the next two decades, owing largely to the widespread use of herbicides with genetically modified corn and soybeans. GMO soya is grown in Amazonian Brazil for the European market, destroying insect diversity in the Amazon (GMO 2016)

Urbanization: Globally, urbanisation is increasing, resulting in destruction of habitat and large habitats are being reduced to smaller areas. Natural habitats are being lost and fragmented as landscapes become more urbanised. Potentially harmful consequences for biodiversity. The Xerces blue butterfly, *Glaucopsyche xerces* gone extinct only due to habitat conversion and urban development main reason. The visiting of the honey-bee populations in disposed cups in commercial beverage shops in rural and urban areas was observed. Honey bee populations that visit these artificial cups for an average of 1225 cups per day never return to their hives. It was recored that 168 bees/ day were visiting and 25,211 dead bees in 30 days, incase of dammer bees (48 bees-single cup/ day). These cups act as 'death traps' for the bees as they fall into the cups and get enmeshed in the syrupy residues, thereby becoming unable to fly out research carried out during 2010 (Chandrasekran et al 2011, Sandilyan 2014)

Deforestation: The total forest area in the world is estimated to be around 4.06 billion hectares. Forests cover 31% of the earth's surface, and from 1990 to 2020, 20 million acres of forest were lost with 2400 trees being cut down every minute. The country's total forest and tree cover is 80.73 million hectares, with a 24.56 percent loss due to tree cutting. India lost 38.5 thousand hectares (14 % loss) of tropical forest in 2019-20. Deforestation is the primary cause of saproxylic beetle extinction in Europe (Nieto and Alexander 2010).

Pollution: Pollution is the second leading cause of insect extinction. Mining of metals, smelting, and other metal-based industries, as well as leaching of metals from various sources such as hazardous waste, toxic waste, garbage dumps, and other metal-based industries, have all contributed to heavy metal pollution.These heavy metals accumulate in the air and spread to agricultural crops in the vicinity of industrialised areas. Critical pollinators, such as honey bees, are directly exposed to metal pollutants when foraging on contaminated nectar and pollen (Xun et al 2018) and suffer from changing behaviour, memory loss, irregular heartbeat, finally dementia when exposed to metal pollution like aluminium (Al) present about upto 200 ppm in sample collected and cadmium (Cd) and Cu compared to unexposed bees (Nisbet et al 2018). Bees are sensitive to lots of toxins 80% reduction in pollinator survival (Thimmegowda et al 2020). One in six species of bees gone extinct in various regions throughout the world. The night-time darkness is a threat to many nocturnal creatures as global light pollution rises. Artificial light “significantly suppressed” the courtship of firefly pairs (Elgert et al 2020). Studies reported that insect population was reduced in hedgerows (47 %) and grassy areas (37 %) along the roadside, because of more use of LEDs lights and this not only disrupt arthropods activities but also contribute to their decline. Nocturnal dung beetle uses moon light from the Milky Way to orient itself but illumination of building lights obscures the dung beetle from galaxy (Foster et al 2021)

Biological factors: Introduction to invasive species found to be on threat on the existing population. Establishment of non native plants leads to reducton of arthropod herbivore loads higher than 90%. The Spread of *Varroa destructor* mite and the small hive beetle, *Aethina tumida* at global leval affects apicultural industry because they transmit viral infections (Vanengelsdorp et al 2012). Through processes like direct predation and parasitism, exotic species introduced for biological control can contribute to the extinction of endemic insects. Planting of exotic trees species along the river's edge of many countries have also impacted negatively on the diversity of dragonflies (Clausnitzer et al 2009). Mosquito control with the larvicide *Bacillus thuringiensis israelensis* (Bti) is still a source of contention, particularly when it comes to the negative effects on non-target organisms such as non-biting midges, of which 50 to 80 percent were killed (Allgeier et al 2019)

Climate change: Ecologists and conservationists are currently working to connect the climatic change that is killing Earth's smallest creatures. Climate change is one of the factors contributing to the decline of butterflies and wild bees (Samways et al 2020). The Paris Agreement is a legally aims to keep deadline for climate change global at one point five degree celcius (1.5°C) rather than earlier aim of two degree celcius (2°C). Climate change determined geographic span dropping to higher than fifty per cent and are projected in vertebrates (26%), plants (44%) and insects (49%), under current pledges, corresponding to 3.2°C warming. At 2°C, reduced to insects (18%), plants (16%), and vertebrates (8%), while at 1.5°C, insects drop to (6%), plants (8%), and vertebrates (4%). When warming is limited to 1.5°C rather than 2°C, the number of species projected to lose more than half of their range is reduced by 66 percent in insects and 50 percent in plants and vertebrates (Warren et al., 2018). Increasing the amount of co2 in the atmosphere, thereby amplifying the Earth's natural greenhouse effect this was happening due much of human activities and makes the earths loosing its small creature. Dung beetles become smaller as CO2 levels rise in the atmosphere. Increased CO_2 in the atmosphere makes dung beetles smaller (Tocco et al 2021). Carbon dioxide levels in the atmosphere are rising, which reduces monarch tolerance and increases parasite virulence by altering the medicinal properties of milkweeds (Dicker et al 2018)

Technological interventions: Mobile telecommunication antenna emits electromagnetic radiation which influences the abundance and composition of wild pollinators. The radiation emitted by towers may impair honey bee navigational skills, preventing them from returning to their hives (Taye et al 2017)

Insects' conservation in 21st century are six interrelated themes: The world is in trouble, as evidenced by the publication of "World Scientists' Warning to Humanity: A Second Notice" (Ripple et al 2017). We must take decisive action on how we manage the planet right now. The future insect diversity should depend on-site adoption, travel through the human-created barriers and final is to die out. It is not an ethical or survival option for insects or humans to go extinct; instead, we must develop conservation methods to ensure that insects survive into the twenty-first century and beyond (Samways 2018):

Theme 1 - Philosophy for insect conservation: First theme implies that we should have intrinsic value on insects, which in turn these insects provide benefits for us in form of bringing bring peace, create mental well-being while seeing these little creatures in the parks, gardens, etc., and also give resources. Because without them, as resources begin to drop, the world would become barren and moving to precarious situation .Simply, we need to look after insects, and they will look after us (Samways 2018)

Theme 2 - Research needed for 21st century insect conservation: Insect conservation research at the operational level focuses on developing new and effective methods for preserving insect diversity, species, and populations. From the standpoint of conservation at species-level, "a species" are the group of individuals in populations, do or do not, interchange of genes. There are two type of population metapopulations and sub population. The viability of populations depending on the flow of genes help them for adapting to existing conditions, but adversely affected by land use fragmentation, insecticidal usage etc. Metapopulation can be affected if gene flow is improper, resulting in an adapt-or-die situation. While subpopulations, the situation is different because they are already separated due to natural barriers. Evolutionarily significant units (ESUs) includes various subpopulations and each units were deserving to be continued existence on its own. *Lycaena dispar dispar* gone extinct, *L. dispar batavus* were under threatened and *L. dispar rutilis* is common and expanding its geographical distribution (Lindman et al., 2015). Despite the fact that ESUs have been reintroduced and should be protected, but it is not real evolutionarily significant units. Genetical research has reported on some species are extremely old, and these species should be protected. Species that have vanished can be resurrected from museum specimens that have been well-preserved. Creating resilient landscapes level conservation with improved functional connectivity, friendly farming system for wildlife which will be resulting in biodiversity friendly in urban areas are the three principles guiding toward insect conservation. Putting people at the centre of environmental issues and growing natural capital could not only continuing to increase the diversity of indigenous species, but also raising the unlimited supply of the focal species. A ten-fold increase would be fantastic for rare and threatened species, while a 100-fold increase would be fantastic for service-providing species like bees for pollination and parasitoids for pest control (Samways, 2018)In the twenty-first century, more research is needed to tailor these principles to local circumstances.

Theme 3- Policy for insect conservation: In terms of policy include dual approaches to conserve insects. Six legged camponion are the part of ecosystem and they also provide important essential services at the national and local levels.

The Aichi biodiversity targets and Convention on Biological Diversity which are specific to insect conservation, whereas for species level conservation, the IUCN provides global level red book list includes insects and NBSAPs -National Biodiversity Strategy Action Plans are working at local level particularly in hotspots areas. Millennium Ecosystem Assessment (MEA) include provisioning, regulating, and cultural services currently provided by insects, which include human consumption of insects and insect therapy, which is becoming increasingly popular globally (Gerlach 2012)

Theme 4-Insect conservation psychology: The relationship between humans and insects is known as insect conservation psychology. Insect conservation is critical to our well-being. Citizen science is the involvement of the general public in the recording, monitoring, and conservation of insects. They activity encourages people to participate in ensuring the future of insects. Insect icons are insects that we are drawn to as children, such as bees, butterflies, and ladybirds. However, not all insects are iconic. Adults, as we grew older, forgot about them in our busy lives. Whlile growing older we will realise that the flies are filthy, the mosquitoes were bother, unwanted and unworthy towards conservational aspects. But we have a pollinator decrease at globally and "the bees were dying," these aspects of realisation is now changing for the better conservation. Another fact is that we are all afflicted with Biophobia. When we overcome our fear of insects, we develop a cultural biophilia for them. Besides biophobia, the another fear factor concerning that there is a loss of essential services particularly pollination done by bees, butterfly, etc. Our reaction to this service loss, alongside biophilia for certain species, is feeding back into insect conservation, which, in turn boosts our sense of happiness. This approach is going to become increasingly important in the twenty-first century (Clayton and Myers 2010)

Theme 5-Insect conservation in practice: Insect conservation is a hands-on activity that relies on solid research and knowledge. In practise, various organisational communities work to conserve insects (Samways, 2018). Many specialist species rely particulat environment to live, so should simulate natural events, these areas require some management. These approaches include eco-friendly agriculture that is organic farming usage of pesticide free cropping, schemes related to agriculture, renovation, eliminate invasive plants species and betterment in urban areas.

Theme 6-*Authentication:* Finally authentication, where we must assess our performance after we have engaged in insect conservation. Determined goal and conducted the research should be done prior to the conservation action and should put research findings into practise, by engaging more in insect conservation psychology. Finally, authentication is a cyclic pathway of success which includes determining resources to achieve the goal, authenticating the goal, and detecting missteps, understanding those missteps in each stage of cyclic pathway, and returning to putting some changes in the goal, and so on. In short, as the twenty-first century progresses, we will place a greater emphasis on a healthy and reliable environment for insect conservation (Samways and Pryke 2016).

CONCLUSION

Ecological balance is the state in which all naturally occurring systems coexist peacefully and without suffering any negative impacts. The wholeness of these natural systems can only be attained if all species, from the smallest to the largest, are given proper attention to ensure their survival. However, the average person either ignores or isn't aware of the significance and prevalence of insects, which belong to the kingdom Arthropoda. However, insects have a crucial role in maintaining the continuation of life on Earth, particularly in the pollination of different plant types. For entomologists and academics, the decline in the increase of the insect population has emerged as a social, scientific, and economic concern. “If we were to wipe out insects alone on this planet, the rest of the life and humanity with it would mostly disappear from land within a few months” said by E. O. Wilson. Time is short for conserving insect diversity so we should take immediate measures to conserve biodiversity. “If conservation of natural resources goes wrong nothing else will go right”, by M. S. Swaminathan.

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Natural Enemy Fauna of Mealybugs (Hemiptera: Pseudococcidae) Infesting Vegetables in Kerala, India

Mithra Mohan and N. Anitha

Department of Agricultural Entomology, College of Agriculture
Vellayani, Thiruvananthapuram-695 522, India
E-mail: mithramohan56@gmail.com

Abstract: An investigation was carried out at different districts of Kerala to identify the natural enemy fauna associated with the mealybugs during 2017-2020. Twenty species of predators belongs to five families under four orders *viz.* Coleoptera, Lepidoptera, Diptera and Neuroptera were recorded from mealybugs infesting vegetables in Kerala. The predominant family was coccinellidae with 16 species under six genera and the majority belongs to the genus *Scymnus*. Among the various predators documented, *Cacoxenus* sp. was recorded the first time as a predator of *Pseudococcus jackbeardsleyi* Gimpel and Milller. Eleven hymenopteran parasitoids belonging to five families were documented from mealybugs, of which the majority belongs to the family Encyrtidae. The record of *Aenasius arizonensis* (Girault) on *Ferrisia virgata* (Cockerell), *Blepyrus insularis* (Cameron) on *P. jackbeardsleyi*, *Leptomastix tsukumiensis* Tachikawa on *Coccidohystrix insolita* Green, *Promuscidea unfasciativentris* Girault on *Coccidohystrix insolita* Green and *Paracoccus marginatus* Williams and Granara de Willink were documented for the first time. The study also identified six hyper parasitoids under the family Encyrtidae, of which *Cheiloneurus nankingensis* Li & Xu was recorded for the first time in India.

Keywords: Mealybugs, Natural enemies, Hyper parasitoids, Pseudococcidae, Kerala

Mealybugs are highly specialized hemipteran phytophagous insects belonging to the second largest family of Coccoidea having more than 2000 species with wide distribution around the world. About 354 species of mealybugs under 62 genera were recorded from southern Asia, of which 105 species were reported from India (Ben-Dov 2013). The globalization accelerated the international trade of commodities which augmented the dispersal of mealybugs to newer regions. The polyphagous mealybug is a menace owing to its greater propensity to attack new host plants in the invaded regions that ultimately resulted in economic damage to crops (Franco et al 2009). As a result of climate changes, many mealybug species hitherto known as minor pest, attained the status of major pest in agricultural crops. The damage caused by the mealybugs is associated with sap-sucking, honeydew production, injection of toxic saliva and transmission of viral diseases (Gullan and Martin 2003). Heavy infestations often led to defoliation, distortion of the stem, stunting and ultimately the death of the plants (Hodges and Hodges 2004).

Management of mealybug is a tedious task due to the presence of waxy coating over the body, concealed growth habitat and clumped spatial dispersal pattern. The repetitive application of broad-spectrum chemicals led to the elimination of natural control agents, development of resistance and residue problems (Subramanian et al 2021). However, bio control agents have strong potential for management of mealybug nymphal stages (Waqas et al 2021). Mealybugs are confronted by a diverse array of natural enemies. A total of 118 species of predators and 79 species of parasitoids were recorded from mealybugs, which signified the importance of biocontrol agents in the population regulation of mealybugs around the world (Shylesha and Mani, 2016). The present study was carried out on exploration of natural enemy species composition of mealybugs in Kerala and that would provide a basis for exploitation of these organisms for future augmentative bio control programmes.

MATERIAL AND METHODS

An exploration of natural enemy fauna of mealybugs infesting vegetable crops in different agro ecological zones of Kerala was undertaken at College of Agriculture, Vellayani during 2017-2021. Detailed investigation across 14 districts of Kerala covering 41 locations were carried out (Table 1) and a location map was created using the software Arc Gis (Fig. 1). During the survey, the adult predators associated with the mealybugs were collected by aspiration, beating or sweeping and killed using ethyl acetate. The specimens were dry preserved in the laboratory and were labeled with details *viz.,* host insect, date of collection, name of the collector, locality and the host plant. The specimens were dried in a hot air oven at 50°C for 5 days and later transferred into an airtight

Table 1. GPS locations of the study area

District	Locations	GPS coordinates
Thiruvanathapuram	Instructional Farm Vellayani	N 8°25'46.6788” E 76° 59'15.02016”
	Balaramapuram	N 8°25'14.01” E 77° 2'25.68”
	Thiruvallom	N 8°24'14.87” E 76° 59'28.23”
	Panagode	N 8°25'22.62” E 76° 58' 17.4252”
	Amabalathara	N 8°27'08.0" E 76°57'02.2"
	Karavaram	N 8°45'09.4" E 76°48'52.9"
	Kulathoor	N 8°32'19.8" E 76°53'07.6"
	Chenkal	N 8°22'23.2" E 77°06'02.1"
Kollam	FSRS, Sadanandapuram	N 8°58'53.9" E 76°48'39.5"
	Poovattor	N 9°03'22.9" E 76°45'02.0"
	Ummannoor	N 8°56'02.6" E 76°48'45.1"
	Paravoor	N 8°48'52.6" E 76°40'11.3"
	Perumkulam	N 9°02'32.4" E 76°45'16.9"
	Kadakkal	N 8°49'48.5" E 76°55'12.2"
Pathanamthitta	Ezhamkulam	N 9°09'10.4" E 76°46'17.6"
	Prakkanam	N 9° 16' 14.88684” E 76° 44'30.62004”
	Enathu	N 9°05'28.4" E 76°45'16.3"
Alapuzha	CPCRI, Kayamkulam	N 9°8'51.02” E 76° 30'50.82”
	Koickal chantha	N 9°11'5” E 76° 33'20.7”
	ORARS, Onattukkara	N 9°10'33.46” E76°30'59.41”
Kottayam	RARS, Kumarakom	N 9°37'39.64” E 76° 25'53.2”
Idukki	CRS, Pampadumpara	N 9°47'56.0" E 77°09'41.5"
	Prakandam	N 9°47'51.79092” E 77° 8'59.36748”
	Valiyathovala	N 9°48'8.45028” E 77° 7'57.04824”
	Mannakkudi	N 9°47'31” E 77° 8'1.58”
	Anchumukku	N 9°48'10.53504” E 77° 7'35.46552”
	Munnar	N 10°05'25.7" E 77°03'15.9"
Ernakulam	KVK, Ernakulam	N 10°02'33.5" E 76°12'24.9"
Thrissur	COH, Vellanikkara	N 10° 32'43.5” E 76° 17'0.4”

Cont...

Table 1. GPS locations of the study area

District	Locations	GPS coordinates
Thrissur	KVK, Thrissur	N 10°32'49.3" E 76°16'05.5"
Palakkad	RARS, Pattambi	N 10°48'40.12812” E 76° 11' 25.82916”
	Muthalamada	N 10°38'14.3" E 76°48'02.4"
Malappuram	KVK, Tavanur	N 10°51'12.36348” E 75°59' 13.15032”
	Vattamkulam	N 10°47'24.6" E 76°01'54.2"
Kozhikode	Kavilumpara	N 11°42'13.2" E 75°47'16.1"
Wayanad	RARS, Ambalawayal	N 11°36'59.8" E 76°12'52.2"
	Manjappara	N 11° 36'14.06196” E 76° 12'35.45856”
	Aandoor	N 11° 35'17.16828” E 76° 1'32.21832”
Kannur	PRS, Panniyur	N 12° 4' 47.6202” E 75° 23'41.84016”
Kasargod	RARS, Pilicode	N 12°12'09.7" E 75°09'53.4"
	COA, Padannakkad	N 12°11'41.9" E 75°11'17.4"

insect box. The immature stages of predators were collected along with the host insect and brought to the laboratory for rearing. The emerged adults were killed and dry preserved. Parasitized mealybugs from the field were collected and kept for adult emergence in plastic containers. The emerged parasitoids were preserved in 75 % ethanol for identification purpose. The specimens were also dry preserved and labeled. The associated mealybug specimens were also collected and stored in 75% alcohol for taxonomic identification. Slide mounted adult female specimens were identified by the keys provided by Williams (2004).

RESULTS AND DISCUSSION

Diversity of predators recorded from mealybugs infesting vegetables in Kerala: Twenty species of predators belongs to five families under four orders *viz.* Coleoptera, Lepidoptera, Diptera and Neuroptera were recorded from mealybugs infesting vegetables in Kerala (Table 2). In the order Coleoptera, Coccinellidae are potential predators of sucking pests and are the most common group widely exploited for biological control programmes around the globe. The present study recorded the family Coccinellidae as the predominant predators of mealybugs in Kerala with 16 species under seven genera. The major genera of coccinellids recorded were *Brumoides*, *Cheilomenes*, *Hyperaspis*, *Pharoscymnus, Cryptolaemus, Nephus* and *Scymnus.*

The genus *Scymnus* was recorded as the most specious group with seven species actively predating on different mealybugs in Kerala. *Scymnus coccivora* Ayyar was prevalent in the vegetable ecosystem predating on *Coccidohystrix insolita* Green. Vidya and Bhaskar (2017) reported that *S. coccivora* was the predominant mealybug predator with a wide host range of six mealybugs in Kerala. Manjushree et al (2019) also documented *Scymnus* sp. as the dominant predator of *Dysmiococcus brevipes* Cockerell in Kerala. Most of the *Scymnus* species were found predating on *C. insolita* whereas certain species were observed in *Pseudococcus jackbeardsleyi* Gimpel and Millller and

Table 2. Predators associated with mealybugs infesting in Kerala

Name of species	Order and family	Prey/associated habit	Associated plants
Brumoides suturalis (Fabricius)	Coleoptera Coccinellidae	*Coccidohystrix insolita*	*Solanum melongena*
		Phenacoccus solenopsis	*Solanum. lycopersicum*
Cheilomenes sexmaculata (Fabricius)	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Cryptolaemus montrouzieri Mulsant	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
		Ferrisia virgata	*Colocasia* sp. *Vigna unguiculata* *Coffea arabica*
Hyperaspis maindroni Sicard	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Pharoscymnus horni (Wiese)	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus coccivora Ayyar	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus sp.1	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus sp.2	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus sp. 3	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus sp. 4	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Scymnus sp. 5	Coleoptera Coccinellidae	*Pseudococcus jackbeardsleyi*	*Codigum varigatum*
Scymnus sp. 6	Coleoptera Coccinellidae	*F. virgata*	*C. varigatum* *Piper longum*
Nephus sp.	Coleoptera Coccinellidae	*Planococcus* sp.	*Theobroma cacao*
unidentified sp.1	Coleoptera Coccinellidae	*F. virgata*	*Cnidoscolus aconitifolius*
unidentified sp. 2	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
unidentified sp. 3	Coleoptera Coccinellidae	*C. insolita*	*S. melongena*
Spalgis epius (Westwood)	Lepidoptera Lycaenidae	*C. insolita*	*S. melongena*
		Planococcus sp.	*T. cacao*
		F. virgata	*S. melongena*
		P. solenopsis	*Hibiscus sp.*
		Paracoccus marginatus	*S. melongena*
Diadiplosis sp.	Diptera Cecidomyiidae	*P. jackbeardsleyi*	*S. melongena*
Cacoxenus sp.	Diptera Drosophilidae	*P. jackbeardsleyi*	*Cordyline terminalis*
Chrysoperla sp.	Neuroptera Chrysopidae	*F. virgata*	*C.aconitifolius*
		C. insolita	*S. melongena*

Ferrisia virgata (Cockerell). The mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant, rare in plain areas of Kerala was observed from Balaramapuram of Thiruvananthapuram district which predated on *C. insolita. C. montrouzieri* was also recorded as the dominant predator of *F. virgata* in high altitude regions of Kerala. Similar results were corroborated by Vidya (2017).

The ape fly, *Spalgis epius* (Westwood) belongs to the family Lycaenidae (Order: Lepidoptera), a potential predator of mealybug, was recorded from *C. insolita, F. virgata, Phenacoccus solenopsis* Tinsley*, Paracoccus marginatus* Williams and Granara de Willink and *Planococcus* sp. The larval stages of the lycaenid were observed as voracious feeder of all stages of mealybug. Dinesh and Venkatesha (2011) documented *S. epius* as a dominant predator of *Planococcus lilacinus* (Cockerell) and *F. virgata* whereas Mani et al (2012) reported *S. epius* as a voracious predator of *P. marginatus* in Kerala. Arya (2015) recorded *S. epius* as a potential predator of *C. insolita* in Kerala.

The present study recorded two dipteran predators of family Cecidomyiidae and Drosophilidae from mealybugs of Kerala. The major mealybug predators in the order Diptera are belongs to the family Cecidomyiidae, Drosophilidae and Syrphidae (Shylesha and Mani 2016). The family Cecidomyiidae are well known for phytophagous species but it also consists of several potential predators of mealybugs. However, studies on the life history and taxonomy of these species are meagre which restrain the use of these species in biocontrol programmes (Hayon et al 2016). The predatory gall midge, *Diadiplosis* sp. was documented as a predator of the mealybug, *P. jackbeardsleyi* in Kerala. The larval stages of the gall midge act as active predator of mealybugs preferably feeding on egg and early instar nymphs. The genus *Diadiplosis*, a cosmopolitan genus, commonly distributed in the tropical regions were reported as a predator of several mealybugs and the species *Diadiplosis martinsensis* Culik and Ventura was recorded from *P. jackbeardsleyi* on pineapple and coffee (Culik and Ventura 2013, Urso-Guimaraes et al 2020). The larval stages of the genus *Cacoxenus* belong to the family Drosophilidae was observed on a new mealybug host, *P. jackbeardsleyi* in Kerala. Mani and Shivaraju (2016) reported that drosophilid predators play a supplementary role in the regulation of mealybug population. The genus *Cacoxenus* was previously reported in Kerala as a predator of D. *brevipes* on pineapple (Manjushree et al 2019). The chrysopid predators are voracious feeders of mealybugs and a single species of *Chrysoperla* was recorded as a predator of the mealybug, *F. virgata* and *C. insolita* in Kerala. Adly et al (2016) reported *Chrysoperla carnea* (Steph.) as a predator of *F. virgata* infesting Guava in Egypt. The *Chrysoperla zastrowii sillemi* Esben-Peterson recorded a predatory efficiency of 66.87 *F. virgata* nymphs in its entire larval period that highlighted the importance of chrysopids in regulating the mealybug population in an ecosystem (Elango et al 2020).

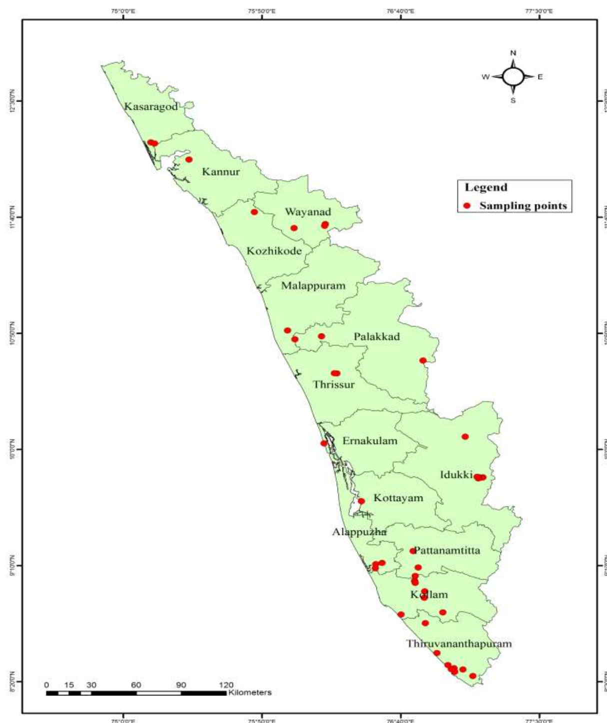

Fig. 1. Study area and locations surveyed for collection of natural enemy fauna in Kerala

Among the different mealybug species recorded from Kerala, the highest number of predators were observed in *C. insolita* (13 species) followed by *F. virgata* (5 species). The major predators on *C. insolita* belongs to the family Coccinellidae with 12 species. The relatively high preference exhibited by coccinellids on *C. insolita* may be due to the predator-prey size relationship as most of the coccinellids were very small in size especially the genus *Scymnus* which was a dominant predator on mealybug *C. insolita.* The morphological peculiarities of the mealybug *viz.,* small size and less mobility favored the easy predation on *C. insolita.* Furthermore, most of the coccinellid grubs were observed to be feeding on the eggs in the long ovisac of *C. insolita* that provided protection from harsh external factors. Kitherian et al (2018) also pointed out that predator-prey size ratio and morphological adaptations aids in a higher predation rate of reduviid predators on *P. solenopsis*.

Diversity of parasitoids of mealybugs: Mealybugs were parasitized by an array of hymenopteran parasitoids and about 11 species belong to five families were recorded from

Kerala (Table 3). The majority of mealybug parasitoids belongs to the family Encyrtidae followed by Eriaporidae in Kerala. Similar observations were also made by Hayat (2006) and Mani and Shivaraju (2016). The family Encyrtidae contains five species belonging to the subfamily Tetracneminae. Among the encyrtids, the most common genera were *Aenasius* comprised of two species *viz., Aenasius arizonensis* (Girault) parasitizing on *P. solenopsis* and *F. virgata* and *Aenasius advena* Compere parasitizing on *F. virgata. A. arizonensis,* an indigenous parasitoid, was recorded as the most successful hymenopteran biocontrol agent of mealybug which recorded 90 per cent parasitism in *P. solenopsis* (Tanwar et al 2011). Bharathi et al (2009) Sudhendu et al. (2010) and Shera et al (2017) also recorded *A. arizonensis* as a specific parasitoid of *P. solenopsis.* The record of *A. arizonensis* on *F. virgata* was recorded for the first time. Nalini and Manickavasagam (2019) recorded *A. arizonensis* and *A. advena* as dominant parasitoids of *P. solenopsis* and *F. virgata* respectively in Tamil Nadu. Similarly, a high rate of parasitization on *F. virgata* by *A. advena* was noted by Ayyamperumal (2019) and Krishnamoorthy et al (2021).

An encyrtid internal parasitoid, *Blepyrus insularis* (Cameron) was recorded from three mealybugs *viz., F. virgata, P. solenopsis* and *P. jackbeardsleyi* from Kerala. Nalini and Manickavasagam (2011) recorded *B. insularis* as a parasitoid of *F. virgata* and *P. solenopsis* in Tamil Nadu. Similar observations were also made by Ayyamperumal (2019). The host-parasitoid association of *B. insularis* and *P. jackbeardsleyi* was recorded for the first time. Two encyrtid

Table 3. Parasitoids associated with the mealybugs infesting vegetables in Kerala

Species	Family	Host insect	Associated plants
Aenasius arizonensis (Girault)	Encyrtidae: Tetracneminae	*F. virgata*	*Hibiscus rosachinensis*
			S. lycopersicum
		F. virgata	*C. aconitifolius*
Aenasius advena Compere	Encyrtidae: Tetracneminae	*F. virgata*	*C. aconitifolius*
Blepyrus insularis (Cameron)	Encyrtidae : Tetracneminae	*F. virgata*	*S. melongena*
			C. terminalis
		P. solenopsis	*Abelmoschus esculentus*
		P. jackbeardsleyi	*S. lycopersicum*
Leptomastix nigrocincta Risbec	Encyrtidae: Tetracneminae	*C. insolita*	*S. melongena*
Leptomastix tsukumiensis Tachikawa	Encyrtidae: Tetracneminae	*C. insolita*	*S. melongena*
Promuscidea unfasciativentris Girault	Eriaporidae: Eriaporinae	*C. insolita*	*S. melongena*
		P. marginatus	*S. melongena*
		F. virgata	*C. aconitifolius*
		P. solenopsis	*Capsicum annuum*
Myiocnema comperei Ashmead	Eriaporidae: Euryischinae	*P. solenopsis*	*C. annuum*
Unidentified	Superfamily Proctotrupoidea	*P. jackbeardsleyi*	*C. terminalis*
Unidentified	Superfamily Proctotrupoidea	*C. insolita*	*S. melongena*
Unidentified	Aphelinidae	*P. jackbeardsleyi*	*C. terminalis*
Unidentified	Pteromalidae	*P. solenopsis*	*C. annuum*

Table 4. Hyper parasitoids associated with the mealybugs infesting vegetables in Kerala

Species	Family	Associated mealybug	Plants surveyed	Location
Cheiloneurus nankingensis Li & Xu	Encyrtidae : Encyrtinae	*P. solenopsis*	*Sesamum indicum*	Kayamkulam
Cheiloneurus sp.	Encyrtidae : Encyrtinae	*P. solenopsis*	*Cucurbita pepo*	Pattambi
Cheiloneurus sp.	Encyrtidae : Encyrtinae	*P.solenopsis*	*S. indicum*	Kayamkulam
Cheiloneurus sp.	Encyrtidae : Encyrtinae	*P. solenopsis*	*Solanum* sp.	Vellayani
Prochiloneurus pulchellus Silvestri	Encyrtidae : Encyrtinae	*C. insolita*	*S. melongena*	Vellayani
Prochilonerus sp.	Encyrtidae : Encyrtinae	*P. solenopsis*	*Euphorbia* sp.	Kayamkulam

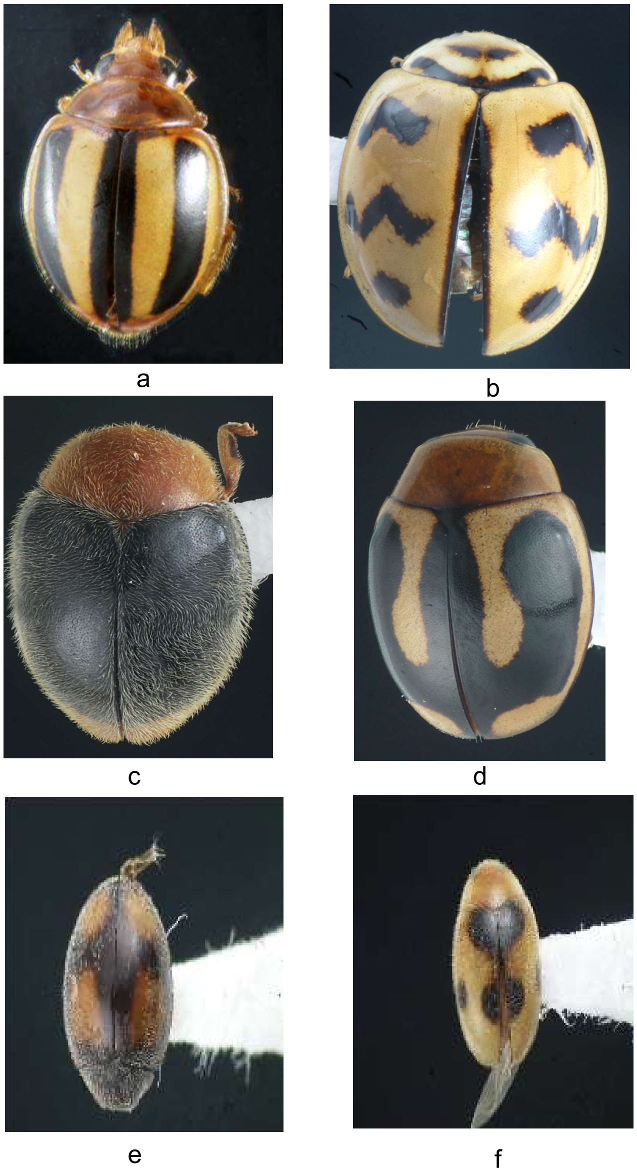

Plate 1. Predators recorded from mealybugs infesting solanaceous and cucurbitaceous vegetables in Kerala. a. *Brumoides suturalis* (10 X), b.*Cheilomenes sexmaculata* (8 X), c.*Cryptolaemus montrouzieri* (8 X), d. *Hyperaspis maindroni* (8 X), e.*Pharoscymnus horni,* (16X) f. *Scymnus coccivora* (20 X)

parasitoids *viz., Leptomastix nigrocincta* Risbec and *Leptomastix tsukumiensis* Tachikawa were recorded from the mealybug *C. insolita*, of which the record of *L. tsukumiensis* on *C. insolita* was documented for the first time in the world. Nalini (2015) and Nalini and Manickavasagam (2011) reported *L. nigrocincta* as a parasitoid of *C. insolita* in Tamil Nadu. The parasitoid, *Promuscidea unfasciativentris* Girault belongs to the family Eriaporidae was observed on mealybugs such as *C. insolita, P. marginatus, F. virgata* and

Plate 1. Predators recorded from mealybugs infesting solanaceous and cucurbitaceous vegetables in Kerala. g. *Scymnus* sp.1 (20X), h. *Scymnus* sp.2 (20X), i. *Scymnus* sp.3 (20X), j. *Scymnus* sp.4 (20X), k. *Scymnus* sp.5 (20X), l. *Scymnus* sp.6 (20X), m. *Nephus* sp. (16 X), n. unidentified sp.1 (16 X), o. unidentified sp. 2 (16 X), p. unidentified sp. 3 (16 X)

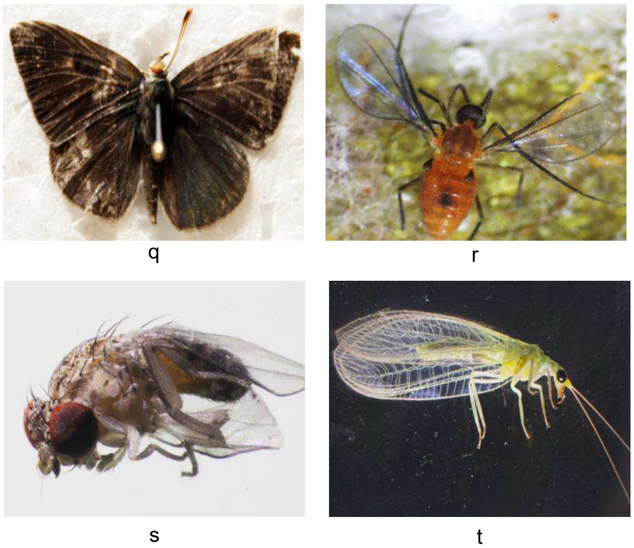

Plate 1. Predators recorded from mealybugs infesting solanaceous and cucurbitaceous vegetables in Kerala. q. *Spalgis epius,* r. *Diadiplosis* sp. (20X), s. *Cacoxenus* sp (10X), t. *Chrysoperla* sp. (8X)

P. solenopsis in Kerala. Jhala et al (2009) and Bharathi and Muthukrishnan (2017) documented *P. unfasciativentris* as the primary parasitoid of *P. solenopsis.* However, Ayyamperumal (2019), Torfi et al (2020) and Chen et al (2021) reported *P. unfasciativentris* as a parasitoid of *A. arizonensis* and a hyper parasitoid of *P. solenopsis.* The host-parasitoid associations of *P. unfasciativentris - C. insolita* and *P. unfasciativentris- P. marginatus* were recorded for the first time in the world. *Myiocnema comperei* Ashmead which belongs to the family Eriaporidae, was also recorded from *P. solenopsis* in Kerala. However, it was recorded as a hyper parasitoid associated with *P. solenopsis* by Ruan et al (2012) and Suroshe et al. (2013) whereas Padmanabhan (2017) and Chen et al (2021) recorded it as a parasitoid of *P. solenopsis* from Kerala and China respectively.

Two species of parasitoids belongs to the superfamily Proctotrupoidea were found to be parasitizing on mealybugs *P. jackbeardsleyi* and *C. insolita* in Kerala. Yasnosh (2016) reported the members of the family Proctotrupoidea from mealybugs*, Pseudococcus* sp. and *Planococcus* sp. Two other parasitoids each from the family Aphelinidae and Pteromalidae parasitizing on *P. jackbeardsleyi* and, *P. solenopsis* were also reported from Kerala during the study. Among the various mealybugs observed in Kerala, *P. solenopsis* was recorded with the maximum number of parasitoids followed by *C. insolita* and *F. virgata*. This may be due to the abundance of these mealybugs in the agro-ecosystems of Kerala.

Diversity of hyper parasitoids: The present study also

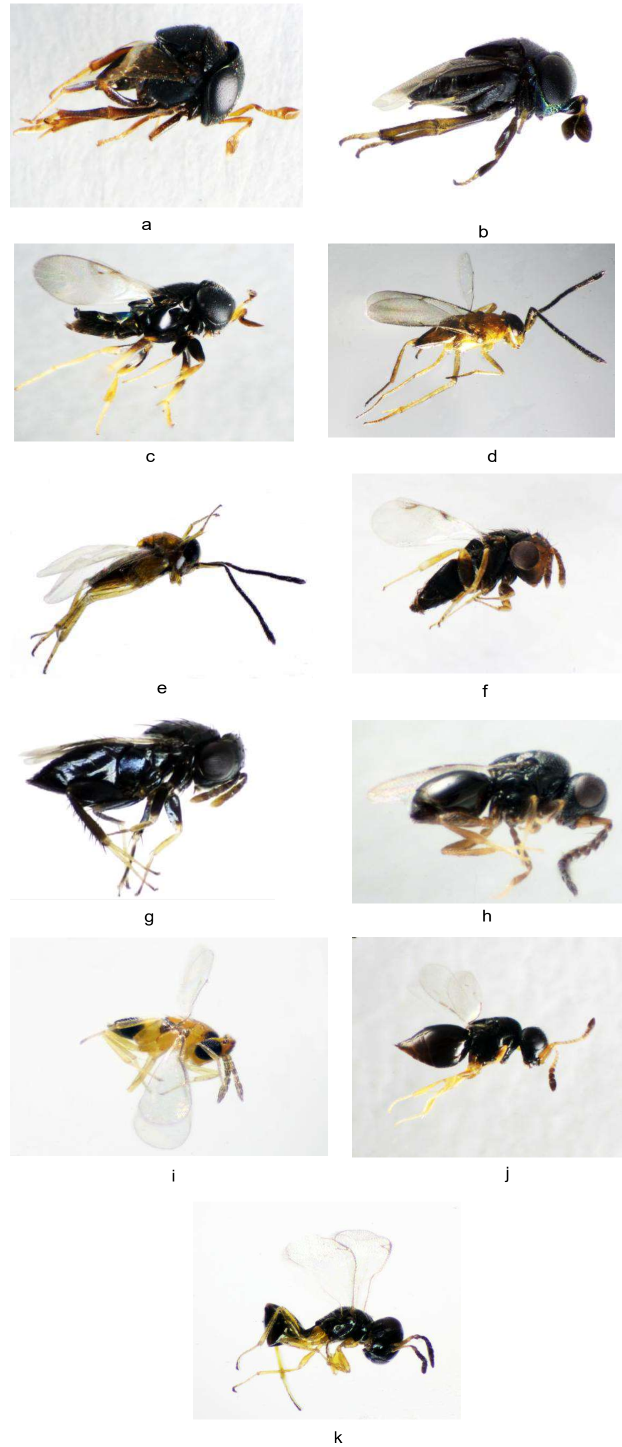

Plate 2. Parasitoids recorded from mealybugs infesting solanaceous and cucurbitaceous vegetables in Kerala. a. *Aenasius arizonensis* (20X), b. *Aenasius advena* (20X), c. *Blepyrus insularis* (20X)*,* d. *Leptomastix nigrocincta* (16X)*,* e. *Leptomastix tsukumiensis* (16X), f. *Promuscidea unfasciativentris* (20 X), g. *Myiocnema comperei* (20X), h. *Superfamily Proctotrupoidea* (25X), i. *Superfamily Proctotrupoidea* (25X), j. *Aphelinidae* (16X), k. *Pteromalidae* (25X)

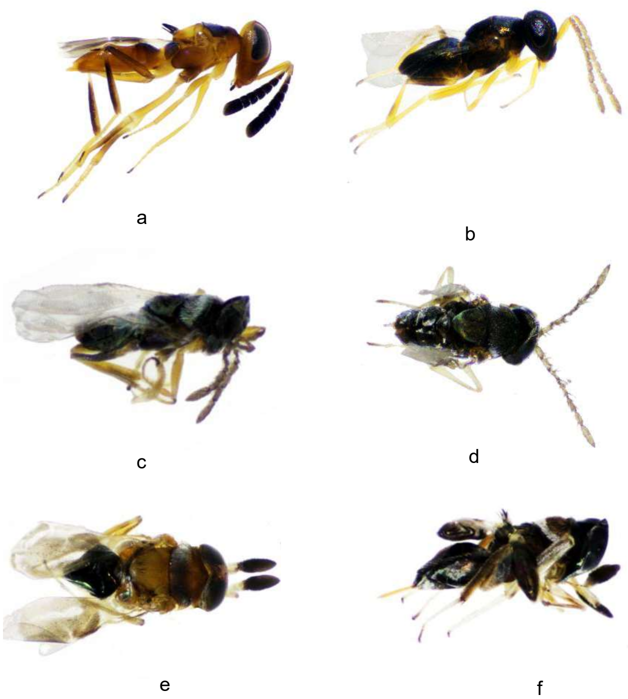

Plate 3. Hyper parasitoids recorded from mealybugs infesting solanaceous and cucurbitaceous vegetables in Kerala. a. *Cheiloneurus* sp. (20X), b. *Cheiloneurus* sp. (25X), c. *Cheiloneurus* sp. (32X), d. *Cheiloneurus* sp. (25X), e. *Prochiloneurus pulchellus* (20 X), f. *Prochilonerus* sp. (20 X)

identified six hyperparasitoids belongs to the family Encyrtidae which comprised of the genera *Cheiloneurus* and *Prochiloneurus* (Table 3). Among these, *Cheiloneurus nankingensis* Li & Xu was reported for the first time in India. The genus *Prochiloneurus* is usually a hyperparasitoid of mealybugs and scale insects *via* parasitization on primary encyrtid parasitoids (Hayat, 2006). Wang et al (2014) documented *Prochiloneurus* sp. as a parasitoid of *A. arizonensis* in China and Ayyamperumal (2019) recorded *Prochiloneurus* and *Chiloneurus* sp*.* as hyperparasitoids of *P. solenopsis* and *F. virgata* through *A. arizonensis* in India. The new hyperparasitoids were found as a menace to the natural biological control methods that kept the mealybug population under check.

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Ecological Association of Diversity of Cow Bugs-Ants and Aphids-Ants Species in Pigeonpea and Safflower Ecosystems

M.S. Sowmyashree, H.T. Prakash* and G.U. Prema[1]

Department of Agricultural Entomology, [1]Department of Plant Pathology
Vijayapura, University of Agricultural Sciences, Dharwad-580 005, India
**E-mai: htprakash4@gmail.com*

Abstract: In pigeonpea, three cow bug species were recorded namely, *Oxyrhachis apicalis* (Anantasubramanian), *Leptocentrus* sp. and *Otinotus* sp. of which, *Otinotus* sp. was the most dominant species (relative abundance=76. 48 %). All cow bugs were actively tended by one species of ant, *Camponotus compressus* Fab. In safflower, two aphid species were recorded *viz*., *Urolecon compositae* (Theobald) and *Aphis* sp. *U. compositae* was the most dominant species (relative abundance= 93.98 %), *Aphis* sp. was found in only tiny patches of field feeding only on leaves. Three ants species found collecting honeydew from aphids by indirect method of tending (*i.e.* by collecting honeydew fell on plant parts) *viz*., *C. compressus*, *Tapinoma melanocephalum* Fab. and *Polyrachis* sp. The different species of cow bug and their associated ants on other host plants *viz. ,Leptocentrus* sp. on brinjal and almond, *Oxyrhachis* sp. on acacia, *Otinotus* sp. on parthenium and were attended by the ant, *C. compressus*. On black nightshade plant (S*olanum nigrum* L.), the cow bug, *Leptocentrus* sp. was found to be tended by the Hunchbacked ant, *Myrmica riabrunnea* Saunders. The aphids, *Pentalonia nigronervosa* Coquerel on banana, *Aphis croccivora* Koch on pigeonpea and *Aphis punicae* Passarini on pomegranate were tended by the ant, *C. compressus*. *Aphis spiraecola* Patch on Siam weed and *Hysteroneura setariae* Thomas on deer tongue grass were tended by *Componotus* sp. In finger millet, the aphid, *H. setariae* Thomas was tended by *T. melanocephalum* Fab. *Aphis croccivora* on cowpea, *A. spiraecola* on Parthenium and *Aphis gossipii* Glover on chilly were tended by *Myrmica riabrunnea* Saunders.

Keywords: Honeydew, Cow bugs, Aphids, Ants, Relative Abundance

In the tropics, membracids species injure a variety of crop plants, including avocado, legumes, coffee, cacao, grape, and papaya. Cow bugs may injure plants, not only through feeding, but also through laying their eggs in host plant tissue by making slits. Treehoppers (Membracidae) provide some of the best studied examples of parenting in insects by frequent maternal eggs guarding. The Membracinae exhibit the full range of social behaviour found among treehoppers, ranging from solitary asocial individuals, aggregations of nymph or adult, to highly developed maternal care in the form of offspring- maternal communication (Lin 2006). All the life stages (egg, nymph and adult) of cow bugs are associated with their host plants. Female insert eggs into different parts of host plant tissues with their strong ovipositor. They may also lay eggs on the surface of the plant tissues. Egg masses are frequently coated with waxy substances derived from accessory glands. Ant mutualism is prevalent among membracine treehoppers and may play an important role in the evolutionary development of sub social behaviour (Lin 2006). Many aphid species like *Dactynotus carthami* (H.R.L.), *Uroleucon compositae*, *Dactynotus orientalis* sp., *Dactyonotus jaceae* (Linn.), *Macrosiphum sonchi* (H.R.L.), *Macrosiphum sonchi* (Linn.), *Macrosiphum compositae* (Theobold), *Macrosiphum* spp. (jaceae), *Myzus persicae* (Sulz), *Aphis fafia* (Scop), *Capitophorus eleagni* (Del. Guer), *Aphis gossypi* Glover, *Aphis nerii* Boyer,*Pleotrichophorus glandolosus* Kalt.*,* *Brachycaudus helichrysi* Kalt. are recorded on safflower (Mallapur et al 2002).

The direct interactions between ants and Homopterans are diverse. A wide range of ant species prey on Homopterans, particularly on coccids and aphids. Some ants prey on one homopteran and tend another: *Formica rufa* (L.), for example, preys on *Drepanosiphum platanoidis* (Schrank) but tends *Periphyllus testudinaceus* (Fernie) (Skinner and Whittaker 1981). Mutualism between ants and sap sucking insects is a well-studied interaction, in which ants stroke cow bugs with their antennae to make them excrete a sugary liquid, called honeydew, which they later consume. *Camponotus compressus* (Fabricius) is a common ant species in Southeast and South Asia, and this ant species is found to interact with many plants sap-sucking hemipterans like aphids and cow bugs. Although *C. compressus*is common and widespread ant, ecology of this ant has been poorly studied. While aspects of the *C. compressus*–aphid mutualism has been reported, the *C. compressus*- cow bugs interaction has not been studied, except for natural history descriptions. Nettimi and Iyer (2015) conducted a preliminary study exploring the foraging strategies of *C. compressus* and its interaction with *Oxyrhachis tarandus*

Fab., a species of cow bug. *C. compressus* ants are reported to follow non-random patterns of searching while foraging on aphid honeydew in cashew inflorescences (Veena and Ganeshaiah 1991), by abandoning poor-quality branches and continuing to forage in richer branches.

Aphids (Aphidoidea: Homoptera) and ants (Formicidae: Hymenoptera) are the best examples of most researched models of mutualistic- relationships in the animal kingdom (Detrain et al 2010). This association of aphid and ants has strong interaction with various host plants. Aphids are one of the major pests of the economically important crops like cotton, castor, pigeonpea, cow pea, etc. Razaq et al (2011) reported 10 to 90 per cent yield loss to the economically important crops in India depending upon crop stage and severity of damage by aphids. It is a well-known fact that an ant colony simultaneously tends numerous aphid species, thus there may be intra or interspecific competition amongst aphid groups for the services provided by the ants. Carbohydrate and nitrogen rich excreta produced by aphids honeydew, which is collected by ants species; in return the ants provide protection and hygiene to aphids. Natural history studies of cow bugs were highly biased toward the New World fauna. Most of the Old-World treehoppers (cow bugs) are still poorly studied except for some species in India (Ananthasubramanian 1996), South East Asia (Lin 2006) and China (Yuan and Chou 2002). The objective of this study is to know the species diversity of cow bugs-associated ants and aphids- associated ants in pigeon pea and safflower ecosystem.

MATERIAL AND METHODS

Sampling and identification of cow bugs, aphids and ants: Cow bugs and their associated ant species were collected from the infested parts of plants at weekly interval. The cow bug and ant population were collected manually with the help of camel hair brush and smaller ant species were collected by using aspirator. The collected cow bugs samples were sorted by observing few differentiating characters like length of horns, color, size and solitary or gregarious feeding nature. Apart from pigeonpea, the population of cow bugs and associated ants were collected from other host plants *viz*. weed plants, horticultural and other field crops. Collected specimens were sent to Biosystematics laboratory, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, (GKVK) Bengaluru, India and National Bureau of Agricultural Insect Resources, NBAIR, Bengaluru, India for their taxonomic identification.

Relative abundance: To measure the percentage of individuals of a particular species of cow bug among all the species, following formula was used:

$$RA = \frac{ni}{N}$$

Where, RA= Relative Abundance, n_i = Total number of individuals in the particular sample / species, N = Total population of all the species

Species diversity of aphids-ants in safflower: The different aphid infested plant parts of safflower like leaf stem, flower head collected from the field collection of aphids and ants done by hand as well as by using camel hair brush. The samples were preserved in 70 per cent ethyl alcohol and sent for identification. Apart from safflower, the population of aphid and associated ants were collected from other host plants *viz*. weed plants, horticultural, other field crops etc. Relative abundance of different species of aphids and ants was calculated by using relative abundance formula mentioned in earlier case with cow bugs.

RESULTS AND DISCUSSION

Species diversity of cow bugs -ants in pigeon pea: Three species of cow bugs recorded from the pigeonpea crop in Vijayapur district, Karnataka, India namely, *Oxyrhachis apicalis* (Ananthasubramanian), *Leptocentrus* sp. and all *Otinotus* sp; all three species were active from flowering to harvesting stage of the crop (Plate 2).

Field observation: Out of three species recorded, *Otinotus* sp. was the predominant, contributing to more than three fourth of cow bugs population. *Otinotus* sp. and *O. apicalis* fed gregariously both as nymph as well as adults, and were greatly attended by ants. *Leptocentrus* sp. was a solitary and most active form. These membracid's presence was easily located by noticing the ant's activity in most of the cases. Adults body color was brown, whereas nymphs were found in both green and brown forms. In adults, pronotum was very well developed, with two horns and pronotum was found to cover most of head region from top and it extended backward.

Biology of cow bugs: Eggs of all three species were elongate in shape and inserted into pigeonpea stem in the ovipositional slits made by female with strong ovipositor. Only part of egg was inserted inside the slits and remaining half was easily visible on bark. *Otinotus* sp. inserted eggs in multiple rows, each row containing 2- 10 eggs, each batch having 25 to 45 eggs and all the rows of eggs were randomly arranged in proximity to each other. *O. apicalis* laid eggs in groups in palmate pattern with densely packed rows and each egg batch was consisting of 45 to100 eggs. Frequent egg guarding behaviour was observed in these cow bugs. Especially in *O. apicalis,* the brooding female found sitting on her egg mass so firmly that eggs remain well concealed. The brooding female was not disturbed even after external stimulus by hand touching (Plate 2). In *Otinotus* sp., the eggs were guarded by more than one brooding female, as the adults were also found more gregarious and deposit eggs masses in proximity to each other. Unfortunately, the brooding behaviour or egg laying pattern of *Leptocentrus* sp. could not be observed in field condition and in *Leptocentrus* sp., there was no such frequent egg guarding behaviour observed. Individual nymphs of *Leptocentrus* sp. were found among gregarious *Otinotus* sp. or *Oxyrhachis apicalis*. The nymphs in all three membracid species observed to be actively attended by ants. In *Leptocentrus* sp., the nymphs were attended more by ants than the adult cow bugs There was difference in time of hatching even for individuals from the single egg mass. So nymphs of different instars in the same group were hatched from same egg mass. The females of *O. rufescens*, *O. brevicornutus*, *O. uncatus*, *O. minusculus* and *O. krusadiensis* guarding the egg masses till the eggs hatch and thereafter the nymphal instars remain very close to the parent females in a gregarious manner, invariably attended by ants. Lin (2006) reported that, membracinae exhibit the full range of social behaviour found among treehoppers, ranging from solitary asocial individuals, aggregations of nymph or adult, to highly developed maternal care in the form of offspring- maternal communication. The antennae were short, filiform and located beneath the eyes, and their structure was identical in all three species. Terminal abdominal segment of both nymphs and adults of all the three species found to possess eversible anal tube which excretes honey dew. The male and female genitalia in all the three species was similar in structure and genital organs were found below the anal tube. Male genitalia have parameres, a U- shaped aedeagus and sternal plate. Female genitalia represented by a strong ovipositor with valvifers (Plate 3).

Relative abundance: Among three species of cow bugs recorded, *Otinotus* sp. was the most abundant species found throughout the experimental period with relative abundance 76.48 per cent, making the most dominant cow bug species in the study area. Relative abundance of second most abundant species, *Oxyrhachis apicalis* was 19.84 percent and *Leptocentrus* sp. was the least abundant species contributing only 3.68 per cent to the total cow bug population. Seni (2021) documented *O. oneratus* as the more abundant cow bug species than *L. taurus*in pigeonpea. Ananthasubramanian (1996) also observed *Oxyrhachis rufescens* (Walker), *O. taranda, O. tuberculus* (Walker), *Otinotus oneratus* (Walker), *Leptocentrus tourus* (Fab.) and *Gargara mixta* (Buckton). Khajuria et al. (2015) recorded two species of cow bugs, *Otinotus oneratus* W. and *O. tarandus* as sporadic pests of pigeonpea. Nair et al. (2017) recorded observed that the activity of cow bug, *L. taurus* started during the vegetative stage of pigeonpea crop and continued up to maturity stage of the pods. These variations in results may be due to change in location of study, weather parameters and host availability. Adult body color was brown in all three cow bug species, whereas nymphs were in both green and brown forms. In adults, very well developed pronotum has two horns, the pronotum covered the most of head region from top and extended backward.

Species diversity of ants associated with cow bug and their behaviour: In pigeonpea ecosystem, all the three species of cow bugs were tended by only one species of ant, *Camponotus compressus* (Fab). there was no species specificity observed for ant attendance. Ant tending behavior is conspicuous and ants were in direct association with the cow bugs by consuming the honeydew directly from the cow bug. Ants were more attracted to cow bugs than any other homopteran pest on pigeonpea, owing to more quantity of honeydew they excrete. Ants were found antennating and guarding the egg batches both in presence and absence of the guarding female cow bug. Ants were also involved in removal of moulted exuviae from the plant twig and consumed the honeydew fell on leaves and stem, thus ensuring hygiene against probable pathogen infection (Plate 4). The honeydew excreted at the site of nymphal aggregation made it difficult for the movement of early instar nymphs by sticking to their legs. But it was absent in the aggregations tended by ants where the nymphs were moving freely. The most important service that ant provided to cow bugs was the protection; whenever the cow bugs were disturbed or attacked, they made vibrational sound, which in turn alerted the ants and an immediate assembling of ants towards the site of disturbance was noticed. Ants' attendance was more abundant in two species of cow bugs, *Otinotus* sp.,and *O. apicalis*. This was due to the gregarious feeding habit of these cow bugs which excreted huge quantity of honeydew in a single place, where ants can consume it with less effort of foraging. In contrast, *Leptocentrus* sp. was less associated with ants as it was found as solitary feeder and actively moves from plant to plant more frequently. Ants attendance was more abundant in two species of cow bugs, *Otinotus* sp., and *O. apicalis*. In contrast, *Leptocentrus* sp. was less associated with ants. Ananthasubramanian (1996) also reported that, large black ant, *C. compressus*, found throughout India as a common species that attended on many species of membracids. Misread al (2003) observed that, the nymphs and adults of *O. tarandus* on mulberry plant were attended by a large number of black ants, *Camponotus compressus* Fab., for the honeydew excreted by them.

Cow bugs and ants association on other host plants: The different species of cow bugs and associated ants on other host plants recorded during this experiment (Table 1). In brinjal, *Leptocentrus* sp. cow bug attended by the ant, *C.*

***Otinotus* sp.** ***Oxyrhachis apicalis* Anantasubramanian** ***Leptocentrus* sp.**

Eggs inside ovipositional slits **Eggs of *O. apicalis*** **Eggs of *Otinotus* sp.** ***O. apicalis* guarding eggs**

Plate 2: Different species of cow bugs and their egg laying pattern on pigeonpea

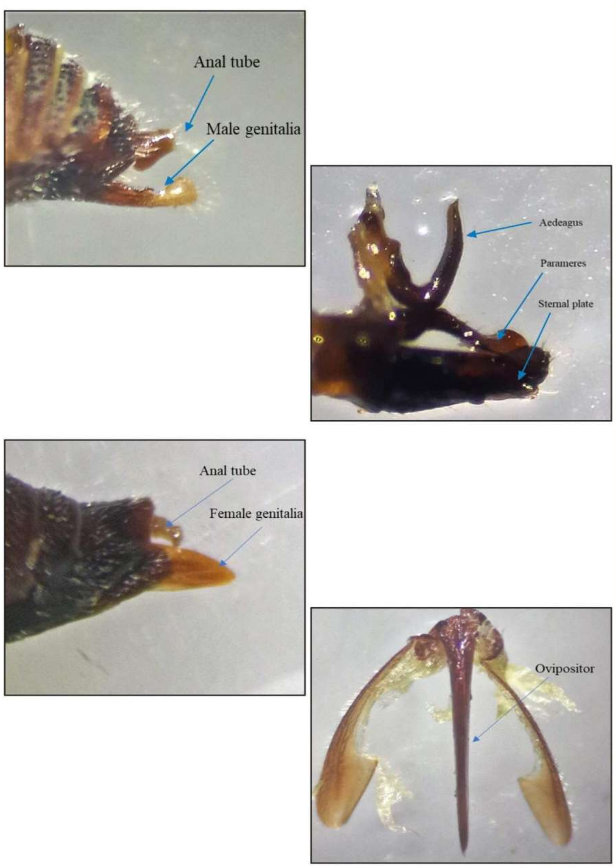


Plate 3: General structure of male and female genitalia in cow bugs

compressus. In Acacia (*Prosopis juliflora* Sw.), the cow bug *Oxyrhachis* sp. was found to be tended by *C. compressus*. On parthenium (*Parthenium hysterophorus* L.) the cow bug, *Otinotus* sp. was tended by *C. compressus*. On almond, *Leptocentrus* sp. cow bug was tended by *C. compressus* ant. On black nightshade plant (*Solanum nigrum*L.), the cow bug, *Leptocentrus* sp. was tended by the Hunchbacked ant, *Myrmica riabrunnea* Saunders (Plate 5).

Species Diversity of Aphids-Ants in Safflower

Field observation: This study recorded two aphid species feeding on safflower *viz*., *Uroleucon compositae* (Theobald) and *Aphis* sp. (Plate 6). The black aphid, *U. compositae* was the dominant species contributing to more than 90 per cent of aphid population on safflower. Adults of this aphid are black and nymphs are blackish brown in color, with well-developed cornicles on 5th abdominal segment. Both adults and nymphs found sucking sap from all parts of plant *viz*., tender leaves, flower head, whole stem and also found feeding on ventral surface of leaves. Severe infestation of this aphid made the safflower stem appear black. *Aphis* sp. was a pale green colour aphid found both in winged and wingless form, and was mainly feeding on tender leaves. The incidence of this aphid species started during seedling stage of crop and reduced towards flowering and crop maturity. Mallapur et al. (2002) reported many aphid species *viz*., *Dactynotus carthami* (H.R.L.), *U. compositae*, *Dactynotus orientalis* sp., *Dactyonotus jaceae* (Linn.), *Macrosiphum sonchi* (H.R.L.), *Macrosiphum sonchi* (Linn.), *Macrosiphum compositae* (Theobold), *Macrosiphum* spp. (jaceae), *Myzus persicae* (Sulz), *Aphis fafia* (Scop), *Capitophorus eleagni* (Del.Guer), *Aphis gossipi* Glover, *Aphis nerii* Boyer, *Pleotrichophorus glandolosus* Kalt., *Brachycaudus helichrysi* Kalt. were recoreded on safflower. These results are in agreement with the present study only with reference to *U. compositae*. The *Aphis* sp. observed in this study was also supported by the report with record of *A. fafia*, *A. gossypi* and *A. nerii* feeding on safflower. Kumar and Chandra (2012) reported the infestation of aphids, *Uroleucon sonchi* (Linn.), *U. composita*e, *Uroleucon carthami* (Linn.) and *Uroleucon gobonis* (Mat.) on the safflower crop right from vegetative to pod stage. Saeidiet al (2015) reported the occurrence of eight species of aphids on safflower *viz*., *Eucarazzia elegans* Ferrari, *Aphis gossypi* Glover, *Aphis nerii* Boyer., *Brachycaudus helichrysi* Kalt., *Hyadaphis sphondyti* Koch., *Pleotrichophorus grandolosus* Kalt. and *U. compositae*. These reports are in line with the present study with reference to occurrence of *U. compositae* and *Aphis* sp. The black aphid, *U. compositae* was the dominant species contributing to more than 90 per cent of aphids population on safflower. The results pertaining to feeding preference and nature of damage by *U. compositae* aphid was supported by the reports of Nivedita et al (2019) where three aphid species *viz*., *U. compositae*, *P. glandolosus* and *B. helichrysi* found to feed on whole safflower plant. In present study, *U. compositae* contributed most to the aphid population on safflower with relative abundance 93.98 per cent. population of *Aphis* sp. was very less which represented only 6.01 percent of total aphid population recorded from sample plants throughout the experimental period. Due to high population of *U. compositae*, whole stem of plant appeared black during its high infestation. In contrast, the presence of *Aphis* sp. was noticed only in few spots of field during all weeks of observations. Saeidi and Adam (2011) opined that, the population of the blood aphids (*U. compositae*) was bigger than that of the green aphids (*P. glandolosus* and *B. helichrysi*) and these two green aphids were mainly seen just as some tiny spots in the fields.

Relative abundance: The species, *U. compositae* contributed most to the aphid population on safflower with relative abundance 93.98 per cent and population of *Aphis* sp. was very less which represented only 6.01 percent of total aphid population recorded from sample plants throughout the experimental period.

Species diversity of ants associated with aphids and their behaviour: Three species of ant's activity was recorded in safflower ecosystem *viz*., *C. compressus*, *Tapinom amelanocephalum* Fab. and *Polyrhachis* sp. *T. melanocephalum* ants found collecting honeydew even on stem where more *U.compositae* aphids were observed. None of these three ant species were directly attended by antennating its abdomen and collected honeydew from *U. compositae.. A*nts collected honeydew which was on leaf surface and soil. The aphid also feeds on ventral side of leaf, there was much honeydew excreted on to the leaf below and on soil (Plate 7). Despite of their huge population with more honeydew production, the *U. compositae* never attract a greater number of ants unlike other aphid species on different crops, which are tended by ants depending on their density, in turn the honeydew providing capacity. None of the three ant species protect or guard the aphids against attacks, ants were simply engaged in honeydew collection. This might be because of high degree of defensive behavior by aphids (which often found oozing defensive fluid from the cornicles and due to composition of safflower sap which made honeydew less palatable.

The ant species, *T. melacephalum* ant was more abundant in safflower field, followed by *C. compressus* and *Polyrhachis* sp. The relative abundance of *T. melanocephalum* was 46.09 per cent, which made most efficient honeydew sourcing ant species in the experimental site. Relative abundance of *C. compressus* and *Polyrhachis* sp. was 41.74 and 12.17 per cent. *Uroleucon* is large genus

Table 1. Species diversity of cow bugs and their associated ants on other host plants

Common name	Host plant	Cow bug species	Tending ant species	Location of collection
Brinjal	*Solanum melongena* L.	*Leptocentrus* sp.	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Acacia	*Prosopis juliflora* Sw.	*Oxyrachis* sp.	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Parthenium	*Parthenium hysterophorus* L.	*Otinotus* sp.	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Black nightshade	*Solanum nigrum* L.	*Leptocentrus* sp.	*Myrmicaria brunnea* Saunders	Tiptur, Tumkur district, Karnataka, India
Almond	*Prunus* sp.	*Leptocentrus* sp.	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India

with 226 species distributed worldwide associated almost entirely with the daisy (Asteraceae) and bellflower (Campanulaceae) families. They either feed on one species or on a few related species.. *Uroleucon* are not usually attended by ants (Dransfield and Brightwell 2021). This report is in line with the present study where none of these three ant species were directly (by antennating its abdomen) found collecting honeydew from *U. compositae*. Only indirect honeydew collection by ants was observed *i.e*., the ants collecting honeydew which was found on leaf surface and soil. These results are deviating with the reports of Tiido (2002) in which, the aphid, *Uroleucon traxaci* (Kaltenbach) on Dandelion plant (*Taraxacum officinale*) unlike other *Uroleucon* spp. was attended by ants. These deviations may be due to change in species and location of study.

Mehrparvar et al (2017) noticed three species of aphids on tansy plant (*Tanacetum vulgare* L.) *viz*., *Metopeurum fuscoviride* Stroyan, an ant tended species, *Macrosiphoniella tanacetaria* Kalt. and *Uroleucon tanaceti* L. were two untended species which were preyed upon by the ants *Lasius niger* (L.) and *Myrmica rubra* (L). Results of the present study are deviating with this report with reference to fact that *U. Compositae* never attacked by any ant species. Despite of their huge population with more honeydew production, *U. compositae* never attract greater number of ants unlike other aphid species on different crops, which are tended by ants depending on their density, in turn the honeydew providing capacity. This might be because of high degree of defensive behavior by aphids or due to composition of safflower sap which made honeydew less palatable. Ant species, *T. melacephalum* was more abundant in safflower field, followed by *C. Compressus* and *Polyrhachis* sp. Relative abundance of *T. melanocephalum* was 46.09 per cent, which made them the most efficient honeydew sourcing ant species in the experimental site. Relative abundance of *C. compressus* and *Polyrhachis* sp. were 41.74 per cent and 12.17 per cent. Neves et al (2011) reports most of ant species tending *Uroleucon erigeronense* (Thomas) on shrub, *Baccharis dracunculifolia* (D.C.) belonged to the genus *Camponotus*. Billick et al (2007) found that, aphids, *Pleotrichopho rusutensis* (Pack and Knowlton) and *Uroleucon escalantii* (Knowlton) on *Chrysothamnus viscidiflorus* (Hooker) were occasionally tended by *Formica obscuripes* (Forel) (Hymenoptera: Formicidae) at field sites in central Colorado. In contrary, no ant species from *Formica* genus were recorded in this experiment. This variation in the ant species associated with aphids was due to presence of different species of ants, their differential foraging behavior and resource specificity in different geographical locations.

Aphids and associated ants on other host plants: Apart from safflower, different species of aphids and their tending ants on different host plants (Table 2) (Plate 8a and 8b). The aphids, *Pentalonia nigronervosa* Coquerel on banana, *Aphis croccivora* Koch on pigeonpea and *Aphis punicae* Passarini on pomegranate were tended by the ant, *C. compressus*. *Aphis spiraecola* Patch on siam weed and *Hysteroneura setariae* Thomas on deer tongue grass were tended by *Componotus* sp. On finger millet, *H. setariae* was tended by *T. melanocephalum*. *A. croccivora* on cowpea, *A. spiraecola* on parthenium and *Aphis gossipii* Glover on chilly were tended by *Myrmica riabrunnea* Saunders. Rakhshan and Ahmad (2015) observed 11 species of aphidocolous ants were associated with *A. craccivora* on Fabaceaeplants. The association of *C. compressus* and *M. bicolor* was greater on

Table 2. Species diversity of aphids and associated ants on other host plants

Host plant	Scientific name	Aphid species	Ant species	Location
Pigeon pea	*Cajanus cajana* (L.) Millsp.	*Aphis croccivora* Koch.	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Banana	*Musa acuminate* Colla.	*Pentalonia nigronervosa* Coquerel	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Pomegranate	*Punica granatum* L.	*Aphis punicae* Passarini	*Camponotus compressus* Fab.	College of Agriculture, Vijayapur, Karnataka, India
Parthenium	*Parthenium histerophorus* L.	*Aphis spiraecola* Patch	*Myrmicaria brunnea* Saunders	Tiptur, Tumkur district, Karnataka, India
Ragi	*Eleusine coracana* L.	*Hysteroneura setariae* Thomas	*Tapinoma melanocephalum* Fab.	Tiptur, Tumkur district, Karnataka, India
Cowpea	*Vigna sinensis* L.	*Aphis croccivora* Koch.	*Myrmicaria brunnea* Saunders	Tiptur, Tumkur district , Karnataka, India
Chilly	*Capsicum annuum* L.	*Aphis gossypii* Glover	*Myrmicaria brunnea* Saunders	Tiptur, Tumkur district, Karnataka, India
Siam weed	*Chromolaena odorata* L.	*Aphis spiraecola* Patch	*Componotus* sp.	Tiptur, Tumkur district , Karnataka, India
Deeer tongue grass	*Dichanthelium clandestinum*	*Hysteroneura setariae* Thomas	*Componotus* sp.	College of Agriculture, Vijayapur, Karnataka, India

Ant removing the exuvium

Honeydew excretion by cow bug nymph

Ant guarding cow bug eggs

Ant tending cow bug nymphs

Plate 4: Different type of interaction between cow bugs and ants

***Camponotus* sp. ant tending *Oxyrhaxhis* sp. on acacia**

***Camponotus compressus* tending *Leptocentus* sp. on brinjal**

***Camponotus compressus* tending *Otinotus* sp. on ber**

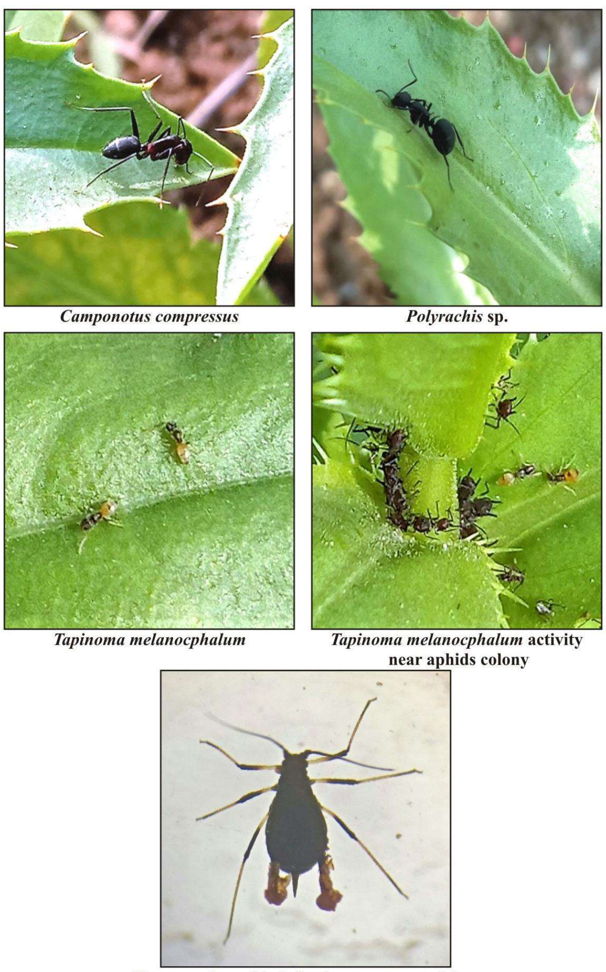
***Myrmicaria brunnea* tending *Leptocentrus* sp. on black nightshade plant**

***Camponotus compressus* tending *Otinotus* sp. on parthenium**

Plate 5: Cow bugs and ants association on other host plants

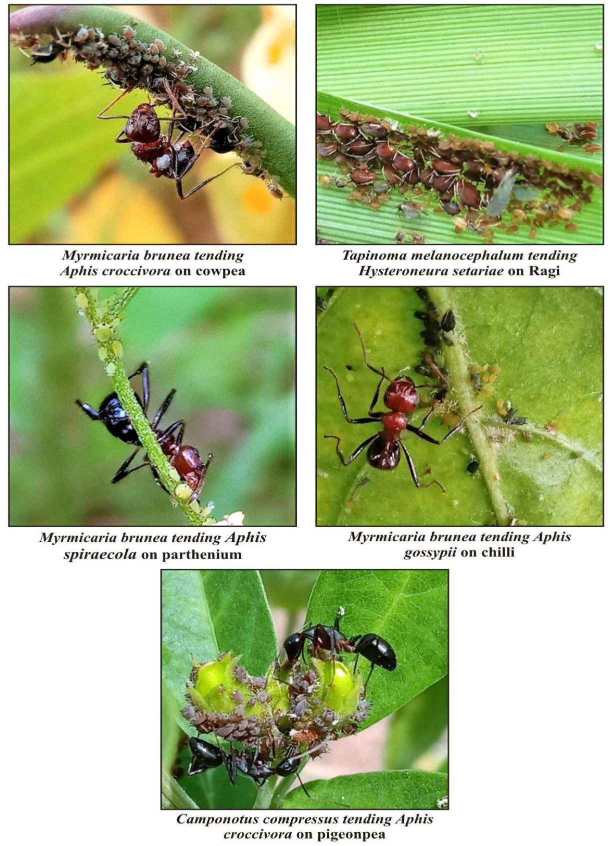
Aphis sp.; *Uroleucon compositae* nymphs; *Uroleucon compositae* winged form; *Uroleucon compositae* wingless form

Plate 6: Different species of aphids on safflower



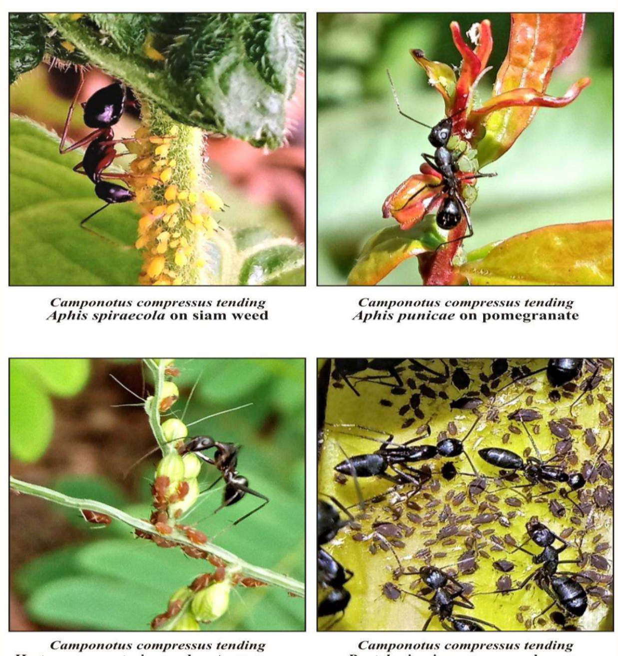
Camponotus compressus; *Polyrachis* sp.; *Tapinoma melanocphalum*; *Tapinoma melanocphalum* activity near aphids colony; *U. compositae* with defensive wax on cornicles

Plate 7: Ants species associated with safflower aphid



Myrmicaria brunea tending Aphis croccivora on cowpea; *Tapinoma melanocephalum tending Hysteroneura setariae* on Ragi; *Myrmicaria brunea tending Aphis spiraecola* on parthenium; *Myrmicaria brunea tending Aphis gossypii* on chilli; *Camponotus compressus tending Aphis croccivora* on pigeonpea

Plate 8a: Aphid- ants association on other host plants



Camponotus compressus tending Aphis spiraecola on siam weed; *Camponotus compressus tending Aphis punicae* on pomegranate; *Camponotus compressus tending Hysteroneura setariae* on deer tongue grass; *Camponotus compressus tending Pentalonia nigronervosa* on banana

Plate 8b: Aphid- ants association on other host plants

all host plants with *A. craccivora* than other aphids. Hosseini et al (2017) reported that aphid, *A. gossypii* was tended by ant, *T. erraticum*. Idechiil et al (2007) recorded ten ant species *viz*., *Anoplolepis gracilipes* Smith*, Camponotus reticulates* Roger*, Cardiocon dylaemeryi* Forel*, Cardiocon dylawroughtonii* Forel*, Paratrechin abourbonica, Pheidole sp., T. melanocephalum, Technomyrmex albipes* Smith*, Technomyrmex sp.* And *Tetramorium bicarinatum* Nylander associated with *Pentalonia nigronervosa* Coquerel on banana (Musaceae), heliconia (Heliconiaceae), and ginger (Zingiberaceae).Three ant species *viz*., *Camponotus navigator* Wilson*, T. melanocephalum and Technomyrmex albipes* were associated with *H. setariae* on several species of grasses. *T. albipes* was observed with *A. gossypii* and a single *Tetraneura* sp. on okra. No ant attendance observed with colonies of *A. craccivora*. This huge difference in aphid-ant association because particular species of ant attending on a particular aphid species in one locality is not very often associated with the same species of aphid in other localities. *A. croccivora* on pigeonpea was attended by *C. compressus*in Vijayapur, while the same species on cowpea was attended by *M. brunnea* in Tumkur.

CONCLUSION

In pigeonpea, three cow bug species were recorded namely, *Oxyrhachis apicalis*, *Leptocentrus* sp. and *Otinotus* sp. of which, *Otinotus* sp. was dominant species. All cow bugs were actively attended by one species of ant, *Camponotus compressus* Fab. In safflower, two aphid species were recorded *viz*., *Urolecon compositae* (Theobald) and *Aphis* sp and *U. compositae* was dominant species found feeding on all arial parts of safflower. *Aphis* sp. was found in only tiny patches feeding only on leaves. Three ants species found collecting honeydew from aphids by collecting honeydew fell on plant parts) *viz*., *C. compressus*, *Tapinoma melanocephalum* Fab. and *Polyrachis* sp.

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Insecticidal Activity of *Tetraclinis articulata* L. Essential Oils on *Tribolium castaneum* (Herbst 1797) (Tenebrionidae: Coleoptera) Adults

KarahacaneTahar, Kaci Zakia, Tirchi Nadia and Abderahmane Omar[1]

Laboratory of Water-Rock-Plants, Agricultural Science Department,
Faculty of Nature and Life Sciences and Earth Sciences, Research,
University Djillali Bounaama, Khemis Miliana, Ain Defla, Algeria
[1]Laboratory for the Protection and Development of Agrobiological Resources, Faculty of Nature and Life Sciences,
University Saad Dahlab Blida 1, Algeria.
E-mail: t.karahacane@uni-dbkm.dz

***Abstract*:** Experimental work consists in highlighting the insecticidal properties of *Tetraclinis articulata* L. essential oils extracted from leaves and dry grains on the adults of *Tribolium castaneum*. under laboratory conditions. The fumigation treatments using four doses of *Tetraclinis articulata* leaf and dry kernels essential oils showed an insecticidal effect on *Tribolium castaneum* adults. High significant difference between grains and dry leaves *T. articulata* essential oils was observed on *T. castaneum* mortality. Mortality of 36.66 to 60% of mortality observed after 48 h of the treatment with dry grains oils. This toxicity reaches 86.66 and 96.66% respectively after the 4th and the 5th day of exposure. Whereas for dry leaves, the mortality was 36.66 to 53.33% after 48h of treatment and 83.33 and 100% mortality respectively on the 4th and 5th day of exposure. The respective LD_{50} and DL_{90} doses for dry grains oils were 10.67 and 15.99 µl; whereas, for dry leaves oils the corresponding values were 9.23 µl for the LD_{50} and 12.55 µl for the DL_{90}. Moreover, the measurement of the shorter time mortality highlights TL_{50} = 36.13 h and TL_{90} = 102.42 h for dry grain and a TL_{50}= 38.02 h and TL_{90} = 108.44 h for treatment based on dry leaves. Contact and ingestion methods can be also investigated to determine the *T. articulata* essential oils activity on other stages of this insect.

***Keywords*:** Essential oil, Inhalation, *Tetraclinis articulata*, *toxicity, Tribolium castaneum*

Damage and loss of wheat, during the storage phase, are caused by many insects, especially Tenebrionidae with *Tribolium castaneum* (Herbst) species is the most widespread one. This insect belongs to Coleoptera order and Tenebrionidae family. Its presence in wheat storage environments can cause grain deterioration and consequently qualitative and quantitative losses. Lee et al (2002) observed that red flour beetle is one of the most serious insect pests in stored grains and processed foods around the world. In Algeria, losses are estimated between 10 to 12% in storage units (Karahacane 2015). Currently, pesticides used to control these pests can have environmental and human health impacts (Ngamo and Hance 2007). The widespread use of synthetic pesticides has led several adverse effects such as food, soil and air contamination with toxic residues, which have side effects on non-target insects and other organisms (Bughio and Wilkins 2004). Faced to this problem, many studies have turned to the use of less toxic products, using non-polluting natural active substances, based on plant extracts, such as essential oils. These botanical pesticides have the advantage of proposing innovative modes of action that can reduce the risk of resistance and offer new ways to design specific molecules for the target (Isman 2006, Isman2008). Many recent studies were coducted in this direction(Mishra et al 2011, Peeyush et al 2011, Toumnou et al 2012, Delim et al 2013, Muhammad et al 2013, Theou et al 2013, Zia et al 2013, Babarinde et al 2014, Ben jemaa 2014, Mobki et al 2014, Ncibi et al 2020, Karahacane and Kaci 2021). This work aims to contribute to the enhancement of this species by evaluating the insecticidal activity of the essential oils of the leaves and seeds of *Tetraclinis articulata* (Vahl) harvested in the region of Khemis Miliana (Algeria).

MATERIAL AND METHODS

The insect mass rearing was carried out in glass container, with a capacity of 500 ml, containing 250 g of wheat. Adults of *T. castaneum* were obtained from stock cultures maintained at the laboratory. The insects were maintained in the rearing chamber at 27±2°C and 60 ±5% RH. Adults aged between 8 and 15 days were used for inhalation toxicity tests. One week after egg laying, adults are eliminated. The eggs give the first generation of adults. By repeating the same process, adults of the second generation, considered homogeneous, were tested with the extracted essential oils.

Collect and plant material preparation: The leaves and grains of *T. articulata* were collected in March 2016 in the region of Khemis Miliana (Algeria) and after harvest; they were dried in the shade for ten days at the laboratory.

Essential oil extraction: The 50 g of plant material (aerial part) was placed in a one-liter flask, filled with distilled water at 1/3 of its capacity. The mixture is heated in a balloon heater. The water evaporates, bringing with it the constituents of the essential oil which are then channeled into a condenser and refrigerated at a temperature of 17°C. to 22°C. to liquefy it again. Thereafter, the oil which floats on the surface of the distillation water is recovered in a dropping funnel. The obtained essential oil was packaged in (2 ml eppendorf) tubes and stored at a temperature of 4°C until use (Karahacane 2015).

Calculation of essential oil yield: *Tetraclinis articulata* essential oil yield was calculated taking into account the mass of extracted essential oil in relation to the mass of the plant material used.

R (%) = [m1/ m2] X100

R: yield of essential oil, **m1**: mass of essential oil, **m2**: mass of the dry plant material.

Toxicity: During our experiments used the doses of 5, 10, 15, and 200 µl of pure oil. They were selected after several preliminary tests. Insecticidal tests by inhalation of essential oils were carried out in Petri dishes of 9 cm diameter and 1.5 cm depth.

Tests were performed on ten non-sexed adults placed in Petri dishes hermetically closed with parafilm. The crude essential oils (4 doses), dropped on a filter paper, were placed in a capsule of 3 cm diameter and 1 cm depth covered by aluminum and closed by a piece of tulle. There was no any contact between the insects and essential oil. The Petri dishes were placed at a temperature of 28 °C and a relative humidity of 70 %. The dead insects were counted on the Petri dishes after 24, 48, 72, 96 and 120 h of treatment. Controls receive no essential oils. To calculate the chemical concentration that kills 50% and 90% of the sample population (LD_{50} and LD_{90}) and the lethal times of 50% and 90% (TL_{50} and TL_{90}), transformed the doses and times into decimal logarithms and probit-corrected mortality percentages (Finney 1971).

These transformations make it possible to obtain regression line equations of the type:

Y = ax + b

Y: probit of corrected mortality.

x: logarithm of dose or time.

a: spawning.

b: constant value.

The corrected deaths were calculated according to the Abbott formula (1925):

MC% = (NIM-NIMT) x100 / (NTI-NIMT)

MC (%): Corrected mortality percentage.

NIM: Number of dead insects in the treated population.

NIMT: Number of dead insects in the control population

The results were interpreted by tests of the variance analysis using two classification criteria (Dagnelie 1975) to study the effect of dose and exposure time of essential oil on the percentage of *T. castaneum* adult mortality.

Factor 1: Dose with 4 levels (D1, D2, D3, and D4).

Factor 2: Exposure time with 5 levels (24h, 48h, 72h, 96h, and 120h).

Statistical analysis was done usingsoftware. In addition, the Newman-Keuls test is used to compare the maximum and minimum mortalities of the different homogeneous groups.

RESULTS AND DISCUSSION

Yield: Yields of *T. articulata* essential oils obtained are 0.37% for dry seeds and 0.2% for dry leaves (Table 1).

Mortality: The percentage mortality of *T. castaneum* has increased significantly using the essential oils extracted from dry grains a dry leaves of *T. articulata* compared to the control. Mortalities vary with dose and time of exposure (Table 2).

Influence of doses and exposure time on mortality: According to the dose and time factor in essential oils extracted from dry seeds and leaves of *T. articulata*, there is a highly significant variation in *T. castaneum* adult mortality rates (Fig. 1 and 2). Figures 1 and 2 show a variability of adult mortality according to the doses and the exposure time.

LD_{50} and LD_{90} : The transformation of the percentages of mortality after 5 days of exposure to probits and the regression of these data as a function of the logarithm of the dose of the essential oils made it possible to obtain the following equations successively Y1, Y2, Y3, Y4 and Y5 for Seeds and leaves (Table 5). The LT_{50} and LT_{90} are calculated directly from the right regression (Table 6) at different doses applied essential oils of seeds and leaves of the studied plant. The best lethal times found for the grains are 36.13 hours for the TL_{50} and 102.42 hours. For dry leaves, they are 38.02 h for the TL_{50} and 108.44 h for the TL_{90} (Table 6) the 4 doses.

Essential oil yield extracted from seeds and leaves of *T. articulate* are respectively 0.37% and 0.2%. Previous work reported that yield of *T. articulata* essential oil in vary from 0.11 to 0.70% for oils extracted from leaves and from 0.32 to 0.41% for oils extracted from twigs. Larabi (2015) observed the yield of the essential oils extracted from leaves of *T. articulata* is 0.11%. Additionally, Bourkhiss et al (2007a) found a yield of 0.22% in the Khmisset region in Morroco. In the same region, a yield of 0.41% was obtained from twigs (Bourkhiss et al 2007b). The higher yield of 0.70% extracted from the leaves, collected at Tetouane in Morocco, (Barrero et al 2005). In Algeria, yields of essential oils extracted found leaves achieved respectively 0.35% in Frenda (Wilaya of Tiaret), 0.75% in EL-Hacaiba (Wilaya of SidiBel Abbes) and 0.78% in Ouled Mimoun (Wilaya of Tlemcen) (Toumi et al 2011).

Several works have revealed that alpha pinène is the main compound of the essential oils of the majority of plant species of the Cupressaceae and in particular the genus *Tetraclinis* and *Juniperus* (Jemli et al 2018, Fierascu et al 2020, Boukraa et al 2022). Inhalation treatment of *T. castaneum* adults with essential oils extracted from seeds and leaves of *T. articulate* showed mortalities exceeding 50%. Mortalities began to appear from the first day with a maximum of 63.66% in dose 4. Then they evolved to 60% on the second day, to arrive at 96.66% at the 5TH day with the dose 4 from seeds oils. With regard to leaves oils, mortalities are also observed from the first day with 36.66%. Then they started to evolve to 53.33% on the second day, 73.33% on the third day, to reach 83.33% and 100% respectively during the 4th day and the 5th day with dose 4. There was no mortality was obtained in the controls. The lethal doses (LD_{50}) are 6.57 and 10.67 µl of the essential oil extracted from the seeds and 5.05 and 6.06 µl of the oil extracted from the leaves. For LD_{90}, only 15.99 µl for seeds and 12.55 µl are retained. The

Table 1. Essential oils yields (%) for grains and leaves of *Tetraclinis articulata* collected from Khemis Miliana, Algeria

Part of plant	Dry matter (g)	Essential oil (g)	Yield (%)
Dry seeds	800	3	0.37
Dry leaves	1500	3	0.2

Table 2. Mortality of *Tribolium castaneum* adults exposed for various periods to essential oils from dry seeds and leaves of *Tetraclinis articulata* (%)

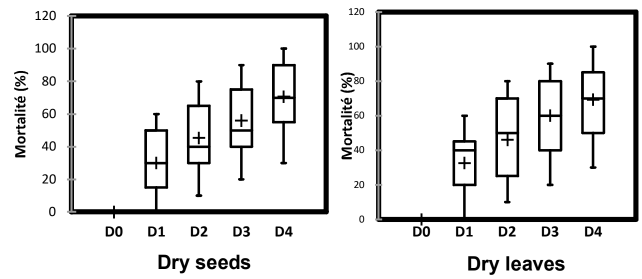
Hours	Dry seeds					Dry leaves				
	T	D1	D2	D3	D4	T	D1	D2	D3	D4
24 h	0	0	13.33	26.66	36.66	0	3.33	13.33	30	36.66
48 h	0	20	33.33	40	60	0	23.33	26.66	43.33	53.33
72 h	0	30	46.66	53.33	73.33	0	36.66	46.66	63.33	73.33
96 h	0	43.33	60	73.33	86.66	0	43.33	66.66	76.66	83.33
120 h	0	56.66	73.33	86.66	96.66	0	56.66	76.66	86.66	100

Table 3. Impact of *Tetraclinis articulate* essential oil doses from dry seeds and leaves on *Tribolium castaneum* mortalities

Parameter	D0	D1	D2	D3	D4
Dry seeds					
Number of observations	15	15	15	15	15
Minimum	0.000	0.000	10.000	20.000	30.000
Maximum	0.000	60.000	80.000	90.000	100.000
Amplitude	0.000	60.000	70.000	70.000	70.000
Aérage	0.000	30.000	45.333	56.000	70.667
Standard déviation	0.000	21.381	22.636	22.928	22.509
Coefficient of variation		0.689	0.482	0.396	0.308
Dry laves					
Numbers of observations	15	15	15	15	15
Minimum	0.000	0.000	10.000	20.000	30.000
Maximum	0.000	60.000	80.000	90.000	100.000
Amplitude	0.000	60.000	70.000	70.000	70.000
Aérage	0.000	32.667	46.000	60.000	69.333
Standard déviation	0.000	19.445	25.014	22.361	23.442
Coefficient of variation		0.575	0.525	0.360	0.327

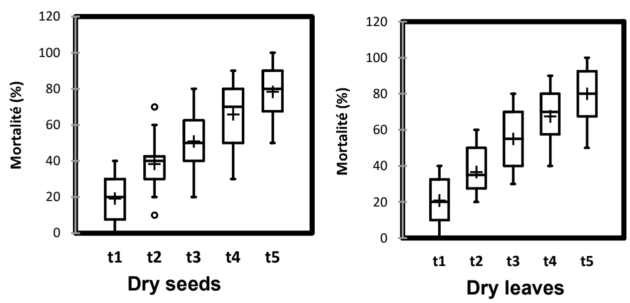
shortest lethal time for killing 50% of the *T. castaneum* population is 52.24 h for the dose 3 and 36.13 h for the dose 4 for the seeds.

Fumigation tests have shown that essential oils obtained from the cones of *Tetraclinis articulata* show high toxicity against *Tribolium castaneum* and *Sitophilus granarius* (Sadik et al 2022). For leaves oils, the TL_{50}s values are 46.66 h for dose 3 and 38.02 h for dose 4. In addition, LT_{90} As for the LT_{90} values were 102.42 and 108.44 hr espectively for grains and leaves oils. Guo et al (2016) found that the essential oil leaves of *Juniperus formosana (*Cupressaceae) same botanical family, as *Tetraclinis* had a strong contact and repellent activity against adults of *T. castaneum* and *Liposcelis bostrychophila* (Liposcelididae- Psocodea) with respective LD_{50}s values of 7.65 g/adult and 81.50g/cm^2., Athanassiou et al (2013) reported a strong insecticidal activity of *Juniperus oxycedrus* (Cupressaceae) leaves essential oils associated with silica gel on adults of *T. confusum* at doses 0.125, 0.250 and 0.5g/kg. Hedjal-chehheb et al (2013) showed that the fumigant action, of *Cupressus sempervirens* essential oil collected from Algeria and Tunisia on *Callosobruchus maculatus* adults after 24 hours of exposure to the dose 37.5 µl. Giatropoulos et al (2013) demonstrated that the leaf essential oils from *Tetraclinis* articulata and other species of the genus *Cupressus* and *Juniperus* gave a strong repulsive activity on *Aedes albopictus* larvae (Culicidae) withs LC_{50}s values ranging from 47.9 to 70.6 mg/l. Harmouzi et al (2016), noted that essential oils, extracted from the leaves and twigs of *T. articulata*, show a toxicity towards *Aphis citricola* which increases with concentration and the exposure time. Kellouche and Chehbab (2014) reported the impact of *T. articulata* essential oils on embryonic, pos-embryonic and



D0, D1, D2, D3 and D4 = Doses of Treatment

Fig. 1. Variability of mortality induced by different doses of dry seeds and leaves *T. articulata* essential oil



t1, t2, t3, t4, and t5 = Time exposures)

Fig. 2. Variability of mortality induced by different times of dry seeds and leaves *T. articulata* essential oil

Table 4. Impact of *Tetraclinis articulate* essential oil doses from dry seeds and leaves of *T. castaneum* mortalities

Parameters	t1	t2	t3	t4	t5
Numbers of observations	12	12	12	12	12
Dry seeds					
Minimum	0.000	10.000	20.000	30.000	50.000
Maximum	40.000	70.000	80.000	90.000	100.000
Amplitude	40.000	60.000	60.000	60.000	50.000
Aérage	19.167	38.333	50.833	65.833	78.333
Standard déviation	15.050	16.422	17.816	18.320	16.422
Coefficient of variation	0.752	0.410	0.336	0.266	0.201
Dry laves					
Numbers of observations	12	12	12	12	12
Minimum	0.000	20.000	30.000	40.000	50.000
Maximum	40.000	60.000	80.000	90.000	100.000
Amplitude	40.000	40.000	50.000	50.000	50.000
Aérage	20.833	36.667	55.000	67.500	80.000
Standard déviation	15.050	13.707	15.667	16.583	17.056
Coefficient of variation	0.692	0.358	0.273	0.235	0.204

Table 5. Regression lines equations obtained for *T. articulata* seeds and leaves

Part of the plant	Right of regression	LD_{50} (µl)	LD_{90} (µl)
Seeds	Y1=7.7502x – 4.8402 (R^2 = 88.7%)	18.60	27.21
	Y2=1.6496x +2.9644 (R^2 = 92.3%)	17.13	102.31
	Y3=2.4401x + 3.3423 (R^2 = 92.5%)	10.67	60.42
	Y4=2.0177x + 3.3491 (R^2 = 94.5%)	6.57	28.35
	Y5=2,4401x + 3.3423 (R^2 = 92.5%)	4,77	15,99
Leaves	Y1=2.5043x + 1.4305 (R^2 = 98.3%)	26.62	86.39
	Y2=1.3500x + 3.2285 (R^2 = 85.8%)	20.52	182.12
	Y3=1.604x + 3.4518 (R^2 = 94.4%)	9.23	57.97
	4=1.8667x + 3.5386 (R^2 = 99.9%)	6.06	29.41
	Y5=3.2392x + 2.7212 (R^2 = 82.8%)	5.05	12.55

LT_{50} and LT_{90}

Table 6. Different equations obtained from the right regression relating to the calculation of TL_{50} and TL_{90} of dry grains and dry leaves of *T. articulata*

Part of the plant	Right regression	LT_{50} (h)	LT_{90} (h)
Seeds	Y1=7.1376x – 9.0706 (R2 = 85.20%)	93.61	141.47
	Y2=2.4208x + 0.5039 (R2 = 98.99%)	71.99	243.23
	Y3=2.3520x + 0.9592 (R2 = 91.16%)	52.24	182.91
	Y4=2.8292x + 0.5922 (R2 = 94.13%)	36.13	102.42
Leaves	Y1= 2.7644x – 0.5519 (R2 = 97.66%)	101.94	296.06
	Y2=2.5993x + 0.18 00 (R2 = 97.04%)	71.50	222.22
	Y3=2.2917x + 1.1752 (R2 = 94.60%)	46.66	168.85
	Y4=2.8123x + 0.5564 (R2 = 90.99%)	38.02	108.44

larval survival on eggs and larvae of *Callosobruchus maculates* when the dose and the time of exposure increase from 0 to 75µl/l of air and from 24 to 96h.

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Characterization of *Phytophthora colocasiae* Raci. Isolates Causing Blight of Colocasia in North-Western Himalayas

Divya Bhandhari and Amar Singh

Department of Plant Pathology, CSK HPKV, Palampur-176 062, India
E-mail: divyabhandhari112@gmail.com

Abstract: Leaf blight and corm rot incited by *Phytophthora colocasiae* is the most devastating disease of colocasia. Twenty isolates of *P. colocasiae* were isolated from the disease samples collected from five districts of Himachal Pradesh and characterized based on morpho-cultural variability, pathogenic variability, chlamydospore formation and mating type. Among different media tested carrot agar was best medium for mycelial growth and sporulation of *P. colocasiae*. On the basis of morpho-cultural characters and pathogenic variability, twenty isolates were categorised into six and five groups, respectively. Only four isolates formed chlamydospores abundantly under dark condition at pH 6.0 in carrot broth incubated at 18°C. Out of twenty isolates 18 were of A_1 mating type whereas, 2 were of mating type A_2. Maximum oospore formation frequency was on carrot agar media at 25°C and was favored by dark conditions.

Keywords: Colocasia blight, *Phytophthora colocasiae*, Colocasia, Oospore, Chlamydospore, Variability

Colocasia (*Colocasia esculenta* (L.) Schott) is a major root crop belonging to family Araceae grown widely for its edible corms and leaves. Colocasia is an important crop of Asian, Pacific, African, American and Caribbean countries (Rao et al 2010). The crop is attacked by several pathogens but colocasia blight incited by *Phytophthora colocasiae* is the most serious disease causing huge yield losses (Misra et al 2008, Adomako et al 2017, Bhandhari et al 2021). The disease was first reported from Java in 1900 (Raciborski 1900). Its occurrence from India was reported by Butler and Kulkarni (1913) whereas Luthra (1938) reported its occurrence from Kangra Valley of Himachal Pradesh. In India very few studies have been conducted on the variability of *P. coloacsiae* (Misra et al 2011, Nath et al 2015, Padmaja et al 2015). The pathogen is known to persist as sporangia in vegetative parts under unfavourable conditions for a few days to two weeks (Fullerton and Tyson 2003) or overwinters as oospores and chlamydospores in infected plant tissue or soil (Nelson et al 2011). There is need to identify critical to investigate the factors that influence the formation of these structures. Sexual reproduction is the primary cause of variation, which may result in the generation of more virulent phenotypes (Goodwin et al 1995). Since, *P. coloacsiae* is heterothallic, it requires both both A_1 and A_2 mating types to produce oospores. However, there is no information on the mating type distribution of *P. colocasiae* in the North Western Himalayas. Current study aimed to characterize the pathogen population in terms of variability, chlamydospore formation, and mating types.

MATERIAL AND METHODS

Collection, Isolation and identification of the pathogen: Different colocasia growing districts of Himachal Pradesh *i.e.* Kangra, Hamirpur, Bilaspur, Mandi and Sirmaur were surveyed during *kharif* 2019 and the leaves showing characteristic colocasia blight symptoms were collected, placed in paper bags and brought to the laboratory (Table 1). The pathogen was isolated from diseased colocasia leaves on potato dextrose agar (PDA) medium. Bits of 2-3 mm size having half portion of diseased and healthy tissue were cut with the help of a sterilized surgical blade. These bits were surface sterilized by dipping in 1 per cent sodium hypochlorite solution for 10-15 seconds and were subsequently washed 3-4 times with sterilized distilled water under laminar air flow. The bits were then placed between two folds of sterilized blotting sheets to remove excess moisture and transferred to PDA Petri plates under aseptic conditions and incubated at 24±1°C in Bio-oxygen demand (BOD) incubator. The culture was purified by hyphal tip method. The identity of the pathogen associated with colocasia blight was established by studying the morpho-cultural traits for the pathogen culture raised on PDA slants by following standard keys (Waterhouse 1963). All isolates were maintained by periodical sub-culturing and after third sub-culture each isolate was inoculated on healthy host and then re-isolated to avoid loss of virulence.

Pathogenicity test: Pathogenicity test was conducted on a Green Stalked variety of colocasia both under net house and laboratory condition as a whole plant assay and detached leaf method, respectively. Inoculum prepared from ten days old culture with zoospore concentration was adjusted to 6×10^4 spore per ml with the help of hemocytometer was sprayed using hand atomizer. As colocasia have waxy leaves tween 20 (0.5%) was added to the inoculum to prevent inoculum run off.

Whole plant bioassay: Colocasia plant at 3-5 leaf stage was sprayed with test pathogen inoculum. After inoculation pots were covered with polyethylene bags and sprayed three times a day with water for three consecutive days to maintain high relative humidity.

Detached leaf assay: Healthy freshly plucked colocasia leaves were placed in Petri plates bedded with cotton and surfaced with moist blotting sheet. Pathogen inoculum was sprayed on leaves and incubated at 24±1°C. The Petri plates were maintained moist by spraying sterilized distilled water at periodical interval of 6-8 hrs to maintain high relative humidity (>90%). Leaves were periodically observed for initiation of symptoms. The experiment was repeated four times for accuracy.

Evaluation of culture media: Five solid media *viz*., potato dextrose agar (PDA), V-8 juice agar (V8), carrot agar (CA), oat meal agar (OMA) and lima bean agar (LBA) were tested to find the best medium for the growth and sporulation of *P. colocasiae.* Media were prepared and sterilized by autoclaving at 1.05 kg/cm^3 (121.6°C) for 20 minutes. Twenty ml of each medium was poured in Petri plates (90 mm), allowed to solidify and inoculated with 5 mm culture discs taken from actively growing margin of 7 days old culture of the *P. colocasiae*. Each media was quadruplicated and incubated at 24±1°C. Radial growth of the obtained colonies was recorded after 3, 5 and 7 days after inoculation (dai). Sporulation was observed on each medium 10 days after inoculation and the number of spores was counted with the help of hemocytometer.

Variability Studies

Cultural variability: Twenty of *P. colocasiae* isolates collected from different areas were used to study cultural variability. Cultural characters of each isolate were studied on CA media. Mycelial bits of 5 mm diameter were cut with the help of cork borer from the margins of the actively growing colony and placed in the centre of the media plates. Inoculated plates were then incubated at 24±1°C in BOD incubator. Each isolate was replicated thrice. Observations were recorded on colony diameter, colour, shape and type of growth seven days after inoculation.

Morphological variability: For morphological studies, mycelial bits of each isolate were taken from seven days old culture. Morphological characteristics such as shape of sporangia, position of sporangia on sporangiophore,

Table 1. *Phytophthora colocasiae* isolates collected from different locations of Himachal Pradesh

District	Location	Variety	Isolate
Kangra	Palampur (32.1109°N, 76.5363°E)	Local	Pc-1
	Palampur (32.1109°N, 76.5363°E)	Sarkaghat Local	Pc-2
	Palampur (32.1109°N, 76.5363°E)	Una Gagret	Pc-3
	Palampur (32.1109°N, 76.5363°E)	Kangra Malan	Pc-4
	Palampur (32.1109°N, 76.5363°E)	Sirmour Nahan	Pc-5
	Palampur (32.1109°N, 76.5363°E)	Ponta Sahib	Pc-6
	Gaggal (32.1586°N 76.2063°E)	Local	Pc-7
	Rakkar (32.1992°N 76.3677°E)	Local	Pc-8
	Baijnath (32.0521°N, 76.6493°E)	Local	Pc-9
Mandi	Joginder Nagar (31.9912°N, 76.7899°E)	Local	Pc-10
	Bharol (31.9341° N, 76.7055° E)	Local	Pc-11
	Bir (32.0456° N, 76.7236° E)	Local	Pc-12
	Ropru (31.7196°N, 76.8519°E)	Local	Pc-13
	Balotu (=32.0053°N 76.4405°E)	Local	Pc-14
Hamirpur	Nadaun (31.7785°N, 76.3445°E)	Local	Pc-15
	Barsar (31.5255°N, 76.4606°E)	Local	Pc-16
	Kohli (*31.7524*°N, *76.34292*°E)	Local	Pc-17
Bilaspur	Barla (31.5480°N, 76.5336°E)	Local	Pc-18
	Ghumarwin (31.4491°N, 76.7048°E)	Local	Pc-19
Sirmaur	Dhaula Kuan (30.4620° N, 77.4817° E)	Local	Pc-20

presence or absence of papillae were recorded. Data on dimensions of sporangia *i.e.* length, breadth and pedicel length were taken by examining 25 randomly chosen sporangia under compound microscope using stage and ocular meter. Length breadth ratio (L:B ratio) was also calculated.

Size (µm) = Number of ocular division × Calibration factor

Where

$$\text{Calibration factor} = \frac{\text{Number of ocular division}}{\text{Number of division of ocular}} \times 100$$

Pathogenic variability: Pathogenic variability among all the isolates was determined by detached leaf method (Dohroo et al 2012). Colocasia leaves of same age group were collected from plants of three local colocasia strains *viz*., Violet Stalked, Green Stalked collected from Palampur and Sarkaghat Local collected from Sarkaghat. Leaves were cut to 4 cm length and placed on moist blotting sheet kept in Petri plates. Spore suspension of 10 µl was inoculated on each leaf disc for each isolate. Leaf disc inoculated with distilled water served as control for each variety and three replications were kept for each treatment. The inoculated leaves were incubated at a temperature of 24±1°C. The leaves were kept moist and inspected daily for the development of symptoms. Subsequently, data on the incubation period and latent period were recorded. The disease score was also calculated using a 0–6-point scale (Little and Hills 1978). Colocasia strains with a disease score between 0 and 2 were categorized as resistant, whereas those with a disease score between 3 and 6 were regarded as susceptible. Further, different isolates were classified as pathotypes based on either of the two reaction types *i.e.* either resistant (R) or susceptible (S) assigned.

Chlamydospore formation: All the isolates of *P. colocasiae* were cultured on modified cleared V-8 $CaCO_3$ liquid medium under submerged condition (Tsao 1971). Mycelial agar plug (1 cm diameter) of each isolate from actively growing margins of 7 days old culture was transferred to a conical flask (250 ml) containing 25 ml cleared V-8 $CaCO_3$ liquid medium. Two replications were kept for each isolate. The flasks were then incubated vertically at 25°C in darkness for 24 hrs and were shaken to fragment hyphae grown out of inoculum plug and incubated further under same conditions. After 6 days, 100 ml of sterile distilled water was added to each flask, mycelial mat sank to bottom of liquid within few seconds and were further incubated vertically at 18°C in darkness for 10 weeks. Chlamydospores were examined for its formation under light microscope, four samples were taken from each isolate randomly. Fifteen arbitrarily selected chlamydospores were measured for diameter and wall thickness for each isolate showing chlamydospore formation.

Mating type: Isolates were paired in order to determine their mating types. Firstly, isolates from different geographic locations were paired to determine A_1 and A_2 mating types. The identified A_1 and A_2 mating types were used as a tester. The type cultures of A_1 and A_2 were paired individually with other test isolates. The mycelial plugs (5 mm diameter) from actively growing margins of 7 days old culture were placed 3 cm apart on carrot agar media at 24±1°C in darkness for 2 weeks. Absence of oospore at the interface of two isolates indicated same mating type and *vice-versa*. Positive control was a cross between two testers. Three replications were kept for each paired culture. Diameter of oospores was measured.

Factors effecting survival spore formation: The isolate that produced abundant survival spore (chlamydospores and oospores) was used to evaluate the effect of different factors *viz*., culture media, light regimes, temperatures and pH. Chlamydospore and oospore formation were evaluated at different temperatures, *viz.,* 15°C, 18°C, 20°C, 24°C, and 30°C. Each experiment was replicated four times. Different liquid media (potato dextrose broth, V-8 broth, carrot broth, oat meal broth, and lima bean broth) for chlamydospore formation and solid media for oospore development were incubated at three different light regimes, *i.e.* light, dark, and intermittent light and dark at 18°C and 24°C, respectively for 10 weeks. Effect of pH on chlamydospore formation was also evaluated at three different pH (6, 7 and 8), which were replicated five times. In each experiment, the total spore formed were recorded by counting the number of spores visualized per microscopic field at 10X.

Statistical analysis: All data obtained were subjected to statistical analysis using OPSTAT software at 5% level of significance. Before analysis the data was transformed wherever found necessary.

RESULTS AND DISCUSSION

Isolation of pathogen and pathogenicity test: Twenty isolates of pathogen were established as pure culture and identified as *Phytophthora colocasiae* Raci. on the basis of morphological characteristics (Fig.2a). Pathogenicity was proved on Green Stalked variety of colocasia with pure culture of all the isolates and maintained for further studies. Symptoms of the disease began as small light brown water-soaked lesion which enlarged rapidly to form large dark brown lesions. Characteristic symptoms of the disease were produced after third and fourth days of inoculation, respectively under laboratory (Fig. 2b) and net house conditions (Fig. 2c). Isolates from different geographical locations were designated as "Pc-1 to Pc-20" (Fig. 1; Table 1).

Evaluation of culture media: CA medium supported the maximum mycelial growth and sporulation of the pathogen (Fig 2d; Fig. 3). Padmaja et al (2015) have also reported that CA medium supported maximum growth in comparison to PDA and other tested media. Tsopmbeng et al (2012) did not find PDA as the best medium for the mycelial growth and sporulation of *P*. *colocasiae*. As the CA medium was determined to be the best, it was utilised in subsequent studies.

Cultural variability: Colony colour of this oomycetous pathogen was observed either white or dull white with circular or irregular colony shape. Majority *i.e.* fourteen isolates showed circular colony while six showed irregular colony. Out of 20 isolates, thirteen produced white colonies and seven showed dull white colony colour. On the basis of mycelial growth pattern, the pathogen isolates were categorised into six groups *viz*., cottony with concentric ring, cottony with dense mycelial growth, cottony with sparse mycelial growth, regular colony, stellate colony and rosaceous colony (Table 2). Maximum growth (mm per day) was observed in Pc-2 (11.3 mm per day) and minimum in Pc-15 (6.7 mm per day). Growth per day also differed within morphological groups. Misra et al (2011) divided *P. colocasiae* isolates to four morphological groups on the basis of mycelial growth namely cottony, petaloid, rosaceous and stellate. However, Nath et al (2015) also characterized *P. colocasiae* isolates into different morphological groups on the basis of colony appearance on potato dextrose agar medium namely cottony, stellate, cottony with concentric rings, plain with irregular concentric rings, irregular pattern, plain, uniform with concentric rings, uniform without pattern and flat with concentric rings. Adomako et al (2018) divided isolates into four morpho-group (MG1 to MG4) on the basis of colony growth pattern *viz*., stellate, petal shaped, sparse cottony and uniform cottony type.

Morphological variability: Sporangia in all isolates were semi-papillate produced terminally with mean pedicel length ranged from 3.5-8.7 µm and ovoid shape sporangia in majority of isolates except few (Pc-3, Pc-10, Pc-12, and Pc-14) which had globose shape. The mean sporangial length and breadth varied from 32-80 µm and 19-47.5 µm, respectively while mean L:B ratio ranged from 1.6-2.2 (Table 1). Isolates Pc-3 and Pc-8 exhibited maximum average length while Pc-10 and Pc-18 had minimum average length. Bandyopadhyay et al (2011) observed sporangia of *P. colocasiae* to be hyaline, papillate and measuring 25 to 55 µm and 15 to 30 µm in length and breadth, respectively. Omane et al (2012) reported that sporangia were ovoid, hyaline, papillate, caducous, 30 to 60 µm × 17 to 28 µm in size having 3.5 to 10 µm pedicel length. Misra et al (2011) mentioned that sporangia of all isolates were semi-papillate and caducous on long pedicel with mean length and breadth of 38 to 60 µm and 18 to 36 µm, respectively. Length breadth ratio ranged from 1.4 to 1.6 and pedicel length from 40-70 µm. Nath et al (2015) observed that sporangia shape of all fifty isolates of *P. colocasiae* varied from ovoid to ellipsoidal with an average length of 32.7 to 52.7 µm and average width of 18.6 to 32.2 µm. Adomako et al (2018) observed sporangium shape of isolates varied from ovoid to globose. However, in the present investigation sporangia of Pc-1, Pc-3, Pc-4, Pc-6, Pc-7, Pc-8, Pc-13, Pc-14, Pc-15 and Pc-19 isolates were exceptionally bigger than reported earlier in literature while sporangia of isolates Pc-10 and Pc-18 were smaller in size. These variations may be attributed to geographical adaptation or indicate speciation. On the basis of morpho-cultural variability 20 isolates were categorized into six morpho groups (Table 4).

Pathogenic variability: The pathogenic behavior of twenty isolates was tested on three local varieties of colocasia *i.e.* Violet Stalked, Green Stalked and Sarkaghat Local by detached leaf method. Most isolates showed lesion initiation 2-3 days after inoculation at 24±1°C (Fig. 5). Initially the inoculated leaves showed yellowish to light brown water-soaked lesions which later turned into dark brown at site of infection, white sporulation of the pathogen was often visible on the lesion after 4-5 days of incubation. The disease severity was calculated in terms disease score and disease reaction was assigned to all the isolates on different varieties (Table 5).

On the basis of disease reaction, various isolates were categorized into five pathogroups *viz*., PcPG1 to PcPG5 (Table 4). Pathogroup PcPG2 was the most virulent and was able to infect all the three colocasia varieties, whereas pathogroup PcPG4 was least virulent. In general, for majority of the isolates of different pathogroup did not show any correlation with the morpho-cultural group but isolate Pc-2 is distinct (PcPG2) and showing relation with the morpho-cultural group (PcG2) also. Nath et al (2015) studied the pathogenic variability of *P. colocasiae* isolates on single susceptible variety and found that majority of isolates had incubation period of 2-3 days and there was no correlation between results obtained from the virulence assay and morphology or geographical origin of the isolates. Adomako et al (2017) studied aggressiveness of *P. colocasiae* associated with colocasia blight in Ghana and reported that mean incubation period of the isolates ranged from 2 to 4 days, irrespective of the morpho-group.

Chlamydospore formation Variable chlamydospore formation was observed in *P. colocasiae*. Out of twenty isolates tested, only four isolates produced chlamydospores (Table 6). Chlamydospores were circular, single, hyaline to pale yellow in colour and were formed both terminally and

Table 2. Morpho-cultural variability of *Phytophthora colocasiae*

Isolate	Cultural characteristics				Morphological characteristics				
	Shape of colony	Mycelial growth pattern	Colony colour	Colony diameter (mm/day)	Shape of sporangia	Length	Breadth	L:B ratio	Pedicel length
Pc-1	Circular	Regular with sparse mycelial growth	Dull-white	8.0	Ovoid	73.0 (62-90.4)	39 (32-46.2)	1.8	3.5 (3.8-6.6)
Pc-2	Circular	Slightly stellate with dense mycelial growth	Dull-white	11.3	Ovoid	61.3 (46.2-77)	32 (15.4-38.5)	1.9	5.1 (4.4-9.6)
Pc-3	Circular	Regular with sparse mycelial growth	Dull-white	8.3	Globose	80.0 (70-85)	47 (40-55)	1.6	4.0 (3.5-6.1)
Pc-4	Circular	Cottony with dense mycelial growth	White	7.4	Ovoid	72.0 (75-85)	36 (29.1-46)	2.0	7.7 (5.9-6.7)
Pc-5	Circular	Cottony with dense mycelial growth	White	7.2	Ovoid	65.0 (55-89)	33.8 (28-37)	1.9	6.3 (5.4-6.7)
Pc-6	Irregular	Cottony with sparse mycelial growth	White	7.5	Ovoid	77.0 (75-87)	39 (27-45)	1.9	6.3 (5.7-7.9)
Pc-7	Circular	Regular with sparse mycelial growth	Dull-white	7.9	Ovoid	75.0 (60-92)	42 (30-45)	1.8	4.2 (4-5.4)
Pc-8	Circular	Cottony with dense mycelial growth	White	7.1	Ovoid	80.0 (57-87)	36.4 (32-45)	2.2	4.3 (3.8-4.9)
Pc-9	Circular	Rosaceous with dense mycelial growth	Dull-white	8.9	Ovoid	45.2 (30-54)	25.0 (20-35)	1.8	8.2 (6-8.7)
Pc-10	Irregular	Cottony with sparse mycelial growth	White	7.1	Globose	32.0 (23-35)	20.0 (18.4-23)	1.6	5.5 (4.5-6.9)
Pc-11	Irregular	Cottony with sparse mycelial growth	White	7.8	Ovoid	55.7 (45-64.4)	29.2 (23-40)	1.8	6.1 (5.2-8.8)
Pc-12	Circular	Regular with sparse mycelial growth	Dull-white	8.1	Globose	62.0 (60-85)	38.0 (32-40)	1.6	3.5 (3.3-5.5)
Pc-13	Irregular	Cottony with sparse mycelial growth	White	7.2	Ovoid	79.0 (67-99)	46.0 (39-50)	1.7	5.9 (3.3-6.6)
Pc-14	Irregular	Cottony with sparse mycelial growth	White	7.0	Globose	78.7 (65-95)	47.5 (40-55)	1.6	5.7 (4.3-6.9)
Pc-15	Irregular	Cottony with sparse mycelial growth	White	6.7	Ovoid	77.0 (61-92.4)	43.2 (30.8-46.2)	1.8	5.4 (3.7-5.9)
Pc-16	Circular	Cottony with concentric ring	White	7.6	Ovoid	59.4 (48-70)	27.0 (24-30.8)	2.1	7.1 (6.2-9)
Pc-17	Circular	Cottony with dense mycelial growth	White	7.1	Ovoid	57.0 (48-69)	25.0 (24-31)	2.2	5.5 (4-6.5)
Pc-18	Circular	Rosaceous with dense mycelial growth	Dull-white	8.5	Ovoid	33.0 (23-38)	19.0 (16-27)	1.7	8.7 (7.5-9.9)
Pc-19	Circular	Cottony with dense mycelial growth	White	7.3	Ovoid	73.0 (62-90.4)	31.0 (28-40)	2.0	5.5 (3.9-5.9)
Pc-20	Circular	Cottony with concentric ring	White	7.9	Ovoid	61.0 (46.2-77)	39.0 (35-50)	2.0	7.5 (6.8-9.3)

intercalary in mycelium (Fig. 5a, b). Chlamydospores were formed abundantly in isolate Pc-18, Pc-19 and Pc-20 while rarely in Pc-15. The diameter of chlamydospores ranged from 26.3-30 µm while wall thickness of chlamydospores ranged from 1.9-2.8 µm. On the basis of chlamydospore formation twenty isolates were divided into 2 groups *i.e.*

Table 3. Grouping of *Phytophthora colocasiae* isolates on the basis of morpho-cultural characteristics

Group	Isolates	Morpho-cultural characteristics
PcG1	Pc-1, Pc-3, Pc-7 and Pc-12	Circular, dull-white colonies with regular sparse mycelial growth pattern. The L:B ratio of the isolates ranged from 1.6-1.8, sporangial length and breadth ranging from 60-92 and 30-55 µm, respectively and pedicel length varied from 3.3 to 6.6 µm. Colony growth per day ranged from 7.9 to 8.3 mm.
PcG2	Pc-2	Circular, dull-white colonies with slightly stellate dense mycelial growth pattern. The L:B ratio of isolate is 1.9, sporangial length and breadth ranging from 46.2-77 and 15.4-38.5 µm, respectively with pedicel length varied 4.4 to 9.6 µm. Colony growth per day was 11.3 mm.
PcG3	Pc-4, Pc-5, Pc-8, Pc-17 and Pc-19	Circular, white colonies with cottony dense mycelial growth pattern. The L:B ratio of isolates ranged from 1.9-2.2 sporangial length and breadth of 48-90.4 and 24-46 µm, respectively with pedicel length varied from 3.8-6.7 µm. Colony growth per day was 7.1-7.4 mm.
PcG4	Pc-6, Pc-10, Pc-11, Pc-13, Pc-14 and Pc-15	Irregular, white colonies with cottony sparse mycelial growth pattern. The L:B ratio of the isolates ranged from 1.6-1.9, sporangial length and breadth of 23-99 and 18.4-55 µm, respectively with pedicel length varied from 3.3-8.8 µm. Colony growth per day was 6.7-7.8 mm.
PcG5	Pc-9 and Pc-18	Circular, dull white colonies with rosaceous dense mycelial growth pattern. The L:B ratio of the isolates ranged from 1.7-1.8, sporangial length and breadth of 23-54 and 16-35 µm, respectively with pedicel length varied from 6-9.9 µm. Colony growth per day was 8.5-8.9 mm.
PcG6	Pc-16 and Pc-20	Circular, white colonies with cottony concentric ring mycelial growth pattern. The L:B ratio of isolates ranged from 2.0-2.1, sporangial length and breadth of 46.2-77 and 24-50 µm, respectively with pedicel length varied from 6.2-9.3 µm. Colony growth per day was 7.6-7.9 mm.

Table 4. Disease reaction of different isolates of *Phytophthora colocasiae* on local strains of colocasia

Isolate	Violet stalked				Green stalked				Sarkaghat local					
	Incubation period*	Latent period	Disease score	Disease reaction	Incubation period	Latent period	Disease score	Disease reaction	Incubation period	Latent period	Incubation period	Latent period	Disease score	Disease reaction
Pc-1	4	5	2	R	3	4	3	S	-	-	-	-	0	R
Pc-2	2	3	3	S	2	3	4	S	3	4	3	4	3	S
Pc-3	-	-	0	R	2	4	3	S	-	-	-	-	0	R
Pc-4	3	4	3	S	2	3	3	S	-	-	-	-	0	R
Pc-5	3	4	3	S	2	3	3	S	-	-	-	-	0	R
Pc-6	4	5	2	R	3	4	2	R	-	-	-	-	0	R
Pc-7	4	5	3	S	4	5	3	S	-	-	-	-	0	R
Pc-8	3	5	3	S	2	4	4	S	-	-	-	-	0	R
Pc-9	3	4	3	S	2	3	4	S	-	-	-	-	0	R
Pc-10	2	3	3	S	2	3	4	S	-	-	-	-	0	R
Pc-11	2	3	4	S	2	3	4	S	-	-	-	-	0	R
Pc-12	2	3	3	S	2	4	3	S	-	-	-	-	0	R
Pc-13	3	5	2	R	2	4	3	S	-	-	-	-	0	R
Pc-14	3	5	2	R	2	4	3	S	-	-	-	-	0	R
Pc-15	2	4	3	S	3	4	4	S	-	-	-	-	0	R
Pc-16	2	4	3	S	2	3	3	S	-	-	-	-	0	R
Pc-17	3	5	3	S	3	5	3	S	-	-	-	-	0	R
Pc-18	3	4	3	S	3	4	3	S	-	-	-	-	0	R
Pc-19	3	4	3	S	3	4	4	S	-	-	-	-	0	R
Pc-20	3	5	3	S	4	5	2	R	-	-	-	-	0	R

* Incubation period and latent period are measured in dai (days after inoculation)

PcC1 include 4 isolates which produced chlamydospore and PcC2 include 16 isolates which did not produce chlamydospore. Misra et al (2011) reported chlamydospores formation in *P. colocasiae.* Out of 14 isolates, 6 isolates were able to produce chlamydospores. Chlamydospores were single, terminal or intercalary and pale yellow in colour with diameter ranging from 18.0 to 34 µm and wall thickness of chlamydospore ranged from 2.0 to 2.5 µm.

Mating type: Mating types were determined for all 20 isolates by pairing isolates in different combination and the cross combination in which oospore were of opposite mating type. Solo cultures were used as control. Combination which formed oospore *i.e.* Pc-18 and Pc-20 and were therefore used as tester. Oospores were amphigynous (Fig. 5c, d) with mean oospore diameter ranging from 23.2 to 29.1 µm. As the oospore diameter of Pc-18 was greater than Pc-20 so, Pc-18 was considered to be A_1 and Pc-20 was considered to be A_2 mating type. These mating types obtained were then crossed separately with other 19 isolates to determine their mating type on carrot agar media. A_1 and A_2 mating types identified as represented in table 6. On the basis of oospore formation isolates were divided into two mating types A_1 types (Pc-1, Pc-2, Pc-3, Pc-4, Pc-5, Pc-6, Pc-7, Pc-8, Pc-10, Pc-11, Pc-12, Pc-13, Pc-14, Pc-16, Pc-17, Pc-18 and Pc-19) and A_2 mating type (Pc-9 and Pc-20). Tyson et al (2007) concluded that out of 54 isolates collected from pacific region, India and South East Asia only 40 isolates were A_2 mating type and 14 did not form oospore with either mating type thus no A_1 or self-fertile isolates were found. Misra et al (2011) reported that all 14 isolates they collected were heterothallic and twelve out which were A_1 mating type while only two isolates were A_2 mating type. Mean diameter of oospores ranged from 18.1 to 30.4 µm and diameter of A_2 mating type isolates were lesser than A_1 mating type. Lin et al (2014) concluded that all 218 isolates collected from islands of Oahu, Kavai, Molokai and Big Island of Hawaii were of A_2 mating type. Mellow et al (2018) reported in Upolu, Samoa that out of 54 isolates 50 isolates were found to be of A_2 and 4 of A_0 type and none of A_1 type when paired with tester *P. nicotianae*.

Factors effecting survival spore formation: The effect of different growth conditions on chlamydospore formation was studied by using isolate Pc-19, a prolific chlamydospore producer among all the isolates. The maximum number of chlamydospores and oospores formation was observed at 18°C and 25°C, respectively (Fig. 6). Among the different media, the maximum number of chlamydospores were formed in carrot broth, followed by oat meal broth, V-8 broth, lima bean broth, and potato dextrose. Among the different media, the maximum number of chlamydospores were formed in carrot broth, followed by oat meal broth, V-8 broth, lima bean broth, and potato dextrose broth. Maximum chlamydospores per microscopic field were recorded in dark conditions, followed by light conditions and intermittent light and dark regimes, and this was the same for each medium. Likewise, maximum oospore formation was recorded in CA medium under dark condition and minimum oospore formation was recorded in PDA medium at intermittent dark and light regimes (Table 8). The highest and lowest numbers of chlamydospore formation were observed at pH 6 and 8, respectively (Fig. 7).

Table 5. Grouping of *Phytophthora colocasiae* isolates on the basis of disease reaction on three colocasia lines

Isolate	Violet stalked	Green stalked	Sarkaghat local	Pathogroups
Pc-1, Pc-3, Pc-13 & Pc-14	R	S	R	PcPG1
Pc-2	S	S	S	PcPG2
Pc-4, Pc-5, Pc-7, Pc-8, Pc-9, Pc-10, Pc 11, Pc-12, Pc-15, Pc-16, Pc-17, Pc-18 & Pc-19	S	S	R	PcPG3
Pc-6	R	R	R	PcPG4
Pc-20	S	R	R	PcPG5

Table 6. Chlamydospore formation in different isolates of *Phytophthora colocasiae*

Isolate	Chlamydospore formation	Diameter (µm)*	Wall thickness (µm)*
Pc-1 to Pc-14, Pc-16 & Pc-17	-	-	-
Pc-15	+	27.0 (26.3-28.1)	2.3 (2.1-2.3)
Pc-18	+	28.0 (27.3-29.6)	2.1 (1.9-2.2)
Pc-19	+	28.0 (27.1-28.7)	2.2 (2-2.4)
Pc-20	+	29.0 (27.8-30)	2.5 (2.3-2.8)

*Average of 15 chlamydospore
+ Chlamydospore formed
- Chlamydospore not formed

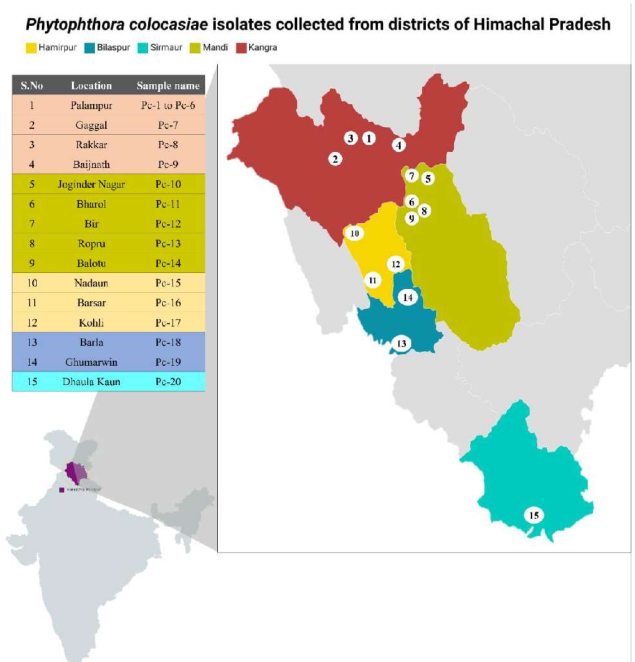


Fig. 1. *Phytophthora colocasiae* isolates collected from different districts of Himachal Pradesh

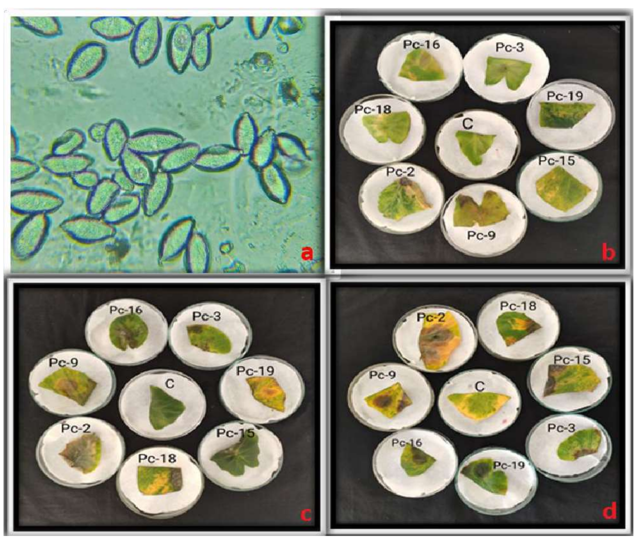


Fig. 4. Pathogenic variability of *Phytophthora colocasiae* a) Microscopic view of sporulation on infected diseased leaves b) Pathogenic variability of isolate Pc-2, Pc-18, Pc-15, Pc-3, Pc-19, Pc-16 and Pc-19 on Sarkaghat Local, c) Green Stalked and d) Violet Stalked colocasia strains

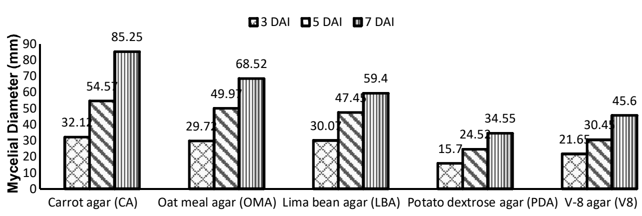


Fig. 3a. Effect of different media on mycelial growth of *Phytophthora colocasiae*

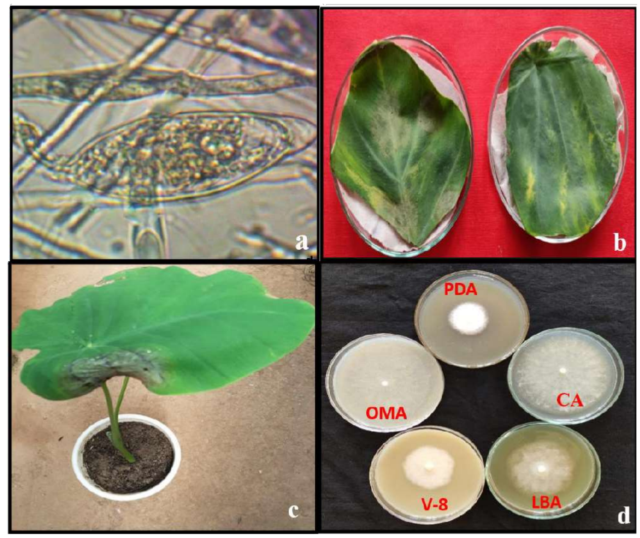


Fig. 2. Pathogenicity test and media study of *Phytophthora colocasiae* a) Hyaline, semi-papillate sporangia of *Phytophthora colocasiae* b) Pathogenicity test of *Phytophthora colocasiae* in laboratory by detached leaf method and c) under net house condition d) Mycelial growth on different media

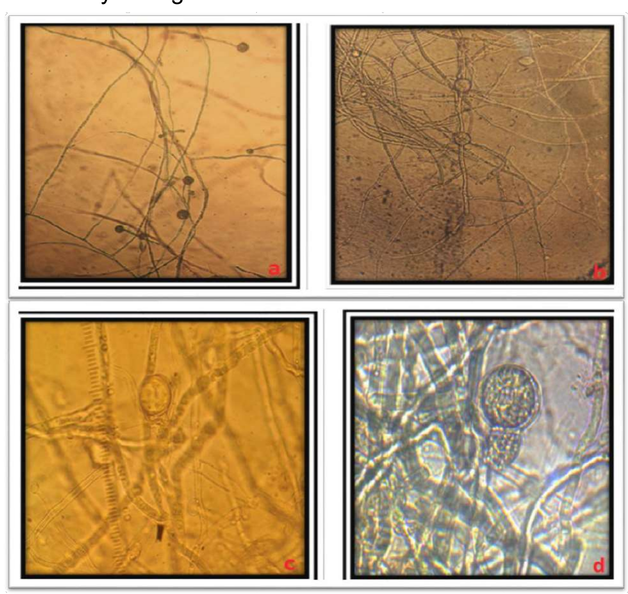
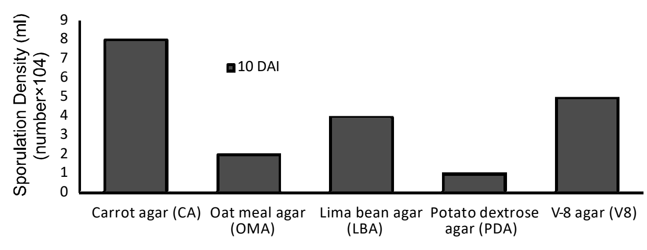


Fig. 5. Chlamydospore and oospore of *Phytophthora colocasiae* Chlamydospore of a) Pc-18 and b) Pc-19 c, d) Oospore under 40X microscopic field



* DAI (Days after inoculation)

Fig. 3b. Effect of different media on mycelial growth and sporulation of *Phytophthora colocasiae*

Table 7. Characterization of mating type of different isolates of *Phytophthora colocasiae*

Isolate	Mating type	Oospore diameter (µm)*
Pc-1	A_1	28.3 (27-29.5)
Pc-2	A_1	28.0 (26-28.7)
Pc-3	A_1	29.0 (27.2-30)
Pc-4	A_1	28.4 (26.5-29)
Pc-5	A_1	27.8 (26.4-28)
Pc-6	A_1	28.0 (25-28.3)
Pc-7	A_1	27.5 (26.1-27.6)
Pc-8	A_1	29.1 (25.6-30)
Pc-9	A_2	23.5 (22-24)
Pc-10	A_1	28.2 (25-28.5)
Pc-11	A_1	29.0 (26-29.4)
Pc-12	A_1	29.0 (25.5-30)
Pc-13	A_1	27.9 (26.3-29.3)
Pc-14	A_1	28.4 (27-29.8)
Pc-15	A_1	28.0 (26-28.3)
Pc-16	A_1	28.1 (27.6-30)
Pc-17	A_1	29.0 (26.8-29)
Pc-18	A_1	29.1 (28.2-30)
Pc-19	A_1	27.8 (27-30)
Pc-20	A_2	23.2 (22.8-25)

*Average of 10 oospore

CONCLUSION

The present study confirms carrot agar as the best medium for mycelial growth and sporulation. It demonstrates that not only the isolates that belonged to different geographical origins but also those obtained from the same area but different colocasia varieties varied with respect to morpho-cultural characters, aggressiveness, and biology. However, some isolates showed few characteristics in common and were classified into six groups on the basis of morpho-cultural variability and five groups on the basis of pathogenic variability. Among the different mycelial growth patterns observed, isolates with a stellate and rosaceous pattern showed faster growth, while isolates showing cottony with sparse and dense mycelium morphology showed slower growth. Isolate Pc-2 was unique with its stellate growth pattern, maximum growth per day, and highest virulence. Twenty per cent of the isolates formed chlamydospores under *in-vitro* conditions, which emphasizes the role of chlamydospores as a survival structure; additionally, their formation was abundant at 18°C, favoring a slightly acidic pH, and in complete darkness. The presence of 18 A_1 and 2 A_2 mating types in Himachal Pradesh highlights the chances of sexual reproduction leading to recombination and hence variability in the pathogen. Oospore formation was seen at its maximum on carrot agar media at 25°C and was favored by dark conditions.

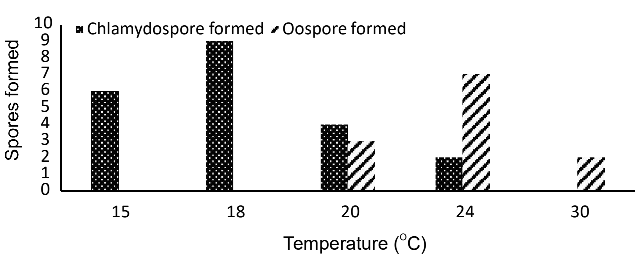


Fig. 6. Effect of temperature on survival spore formation in *Phytophthora colocasiae*

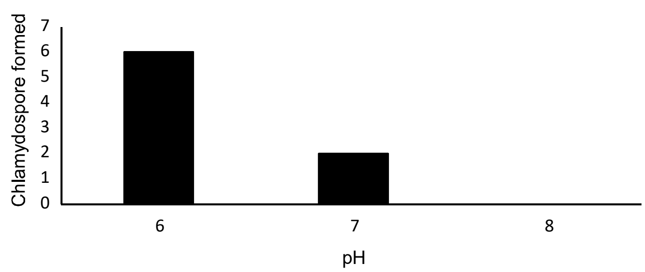


Fig. 7. Effect of pH on chlamydospore formation in *Phytophthora colocasiae*

Table 8. Effect of different media and light regimes on survival spore formation in *Phytophthora colocasiae*

Media	Chlamydospore formation (Broth)			Oospore formation (Solid media)		
	Dark	Light	Intermittent light and dark	Dark	Light	Intermittent light and dark
Potato dextrose	2	1	0	2	0	1
Oat meal	9	8	6	5	1	2
V-8	6	3	2	6	2	4
Carrot	15	6	4	9	5	7
Lima bean	3	1	1	4	0	0
CD (p=0.05)	0.708	0.589	0.708	0.76	0.735	0.589

* Mean of 15 microscopic field at 10X

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Effect of Different Drying Treatments on Functional and Nutritional Composition of Oyster Mushroom (*Pleurotus ostreatus*) Powder

V. Pataiya, D. Bhati*, S.K. Singh[1], D. Maurya[2], D.B. Tyagi[3] and S. Sharma[4]

School of Agriculture, ITM University Gwalior-474 001, India
[1]School of Agriculture, Lovely Professional University, Phagwara-144 001, India
[2]School of Agriculture Science, GD Goenka University, Gurugram-122 103, India
[3]Faculty of Agriculture Science, Mandsaur University, Mandsaur-458 001, India
[4]School of Allied Health Science, Jaipur National University, Jaipur-302 017, India
**E-mail: bhati.dashrath.1@gmail.com*

Abstract: Present study aimed to determine the effect of different drying treatments on functional, nutritional and organoleptic properties in dried oyster mushroom (*Pleurotus ostreatus*) powder. The fresh oyster mushrooms were dried under sun drying, vacuum drying @ 70°C, freezer drying@ -40°C, hot air drying@ 55°C and tray drying@ 50°C. The hot air drying recorded maximum oil holding capacity, hydration capacity, TSS and total sugars 2.47 gm/gm, 4.36 gm/gm, 3.40°B, 10.04 per cent, respectively. The proximate composition protein content was also high in hot air drying (17.10 gm/100gm) followed by vacuum drying @ 70° and freezer drying@ -40°C. The energy content was maximum in sun drying (333.02 Kocal/100gm) followed by tray drying@50°C and freezer drying@ -40°C. Calcium, sodium, potassium and magnesium were highest in hot air-drying method.

Keywords: Mushroom Flour, Processing, Mycelium, Sensory and functional properties

The very popular name of oyster mushrooms is of *Pleurotus* genus and among all the mushrooms it consumed throughout the world. Mushrooms are low in calories, cholesterol and fat with good quality proteins. Besides this it contains minerals, vitamins, and dietary fibers. The highly perishable nature of fresh mushrooms is attributed to their high moisture content (85%-95%) which favors microbial activities, high respiration rate, delicate texture, and high enzymatic activities (Jiang 2013). Higher moisture content leads to reduced shelf life of mushrooms and therefore, distribution and marketing as fresh produce limits consumption. The methods such as cold storage, drying, freezing, modified atmosphere packaging, controlled atmosphere storage, and canning are applied to extend the shelf-life and maintain the postharvest quality of mushrooms (Candir et al 2019). Drying is one of the oldest methods of preservation and mushrooms are also preserved by using this method. For proliferation and growth microbes required moisture. Free water is lost during drying process and thereby it slows down biological reactions and enzymatic activity thus results into longer keeping life of the mushrooms. The dried food products when packed and stored in air tight containers can help in continent for transportation. There are various methods used for the drying of the food products. However, method of drying affects the different functional and nutritional profile of the food. Therefore, the present study was planned to study the different drying treatments effect on oyster mushrooms' functional properties and nutritional components.

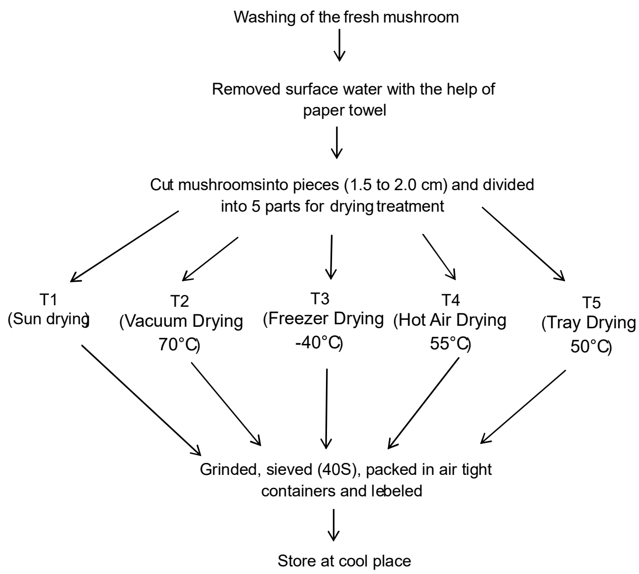
MATERIAL AND METHODS

Fresh mushrooms were procured in single lot from local market of the Gwalior, Madhya Pradesh, India and washed with tap water 3-4 times to clean the foreign material present on the surface of the mushroom. The extra water on the surface of the washed mushroom was cleaned with help of paper towel. The washed and cleaned mushroom was further subdivided into five groups (Flowchart 1). All the dried samples were further grided with the help of grinder for analysis.

Functional Properties

TSS: The homogenized sample was used for determination of T.S.S (°Brix) with the help of hand refractometer. The 5gm dried mushroom powder sample was dissolved in 50 ml of distilled water and left for 30 minutes. This was filtered with the filter paper and filtrate was used for the analysis with the help of digital refractometer (Rangana 2012).

Oil holding capacity (OHC): This was determined by a slight modification of the method described by Zhang *et al* (2011). In one gm mushroom powder, 20 gm of refined oil was added. This was mixed by stirring the mixture in vortex for 30 min. This solution was centrifuged at 4200 rpm for 30 min.



Flowchart 1. Drying treatment of mushroom for analysis and further study

The supernatant was removed and weighed. The results were expressed in gm/gm.

Hydration capacity (HC): Hydration capacity was determined standard method suggested by Mateos-Aparicio (2010). The 0.5g of sample was added in a test tube and 10 ml water was poured into it. This solution was starred and left to hydrate for 30 min. After 10 minutes the mixture was centrifugated at 4200 rpm and supernatant was collected after its settlement. The collected sediment was weighed and results were expressed in gm/gm.

Estimation of sugars: Total sugars and reducing sugar were estimated in Nelson, 1944. However non-reducing sugars were estimated by the difference of total and reducing sugars.

Evaluation of Proximate composition of treated mushroom powder: Moisture, crude protein, crude fat, crude fibre, total minerals, of the samples was determined AOAC, 2009. Carbohydrate content was calculated by difference method and energy content the physiological fuel Mudambi et al (1989)

Vitamin D estimation: It was estimated in two phase viz sample extraction and final estimation. Vitamin D in the sample was extracted by 99% ethanol (v/v) and 50% potassium hydroxide (2:1; w/v). The mixture was saponified for 30 min under reflux at 85°C. The organic layer was evaporated to dryness at 50°C in rotary evaporator. The dried sample extract was dissolved in 2 ml of a mixed solution of eluent (methanol/ acetonitrile = 75:25 v/v) and isopropyl alcohol (2:1 v/v). The UV detection of elute for Vitamin D was performed at 264 nm (Sarioglu et al 2001).

Estimation calcium, sodium, potassium and magnesium: The sample was prepared by using wet ash method by digesting the samples with 5 ml of diacid mixture (HNO3 and sulfuric acid) until its turn cleared. The volume was made up 50ml with the help of deionized water. The calcium, sodium, potassium and magnesium were estimated by using AAS (Bishnoi and Brar 1988).

Organoleptic evaluation: The dried mushroom powder was given to 15 panel members for organoleptic evaluation. The taste, flavour, aroma, overall acceptability was analysed organoleptically. On the basis of organoleptic evaluation of differently dried mushroom powder (Larmond 1970).

RESULTS AND DISCUSSION

Functional properties: The OHC of the treated mushroom powder ranged between 2.43 gm/gm to 2.47 gm/gm (Table 1). The HC and TSS was maximum in T4 i.e. 4.36 gm/gm and 3.40 °B respectively. Similarly, percent total sugars and non-reducing sugars was high in T4 i.e. 10.04 and 5.60 respectively. Physical properties of mushroom powders were significantly affected by different drying methods. This may be due to different temperature and duration of exposure to the temperature. The microtomographic images of oyster mushroom dried under different method had recorded heterogeneous structure and number of pores (Piskov et al 2020). Different drying treatments can influence physical properties as well as composition of the raw material (Dalmau et al 2017, Ucar and Karadag 2019).

Proximate composition of oyster mushroom: The proximate composition of oyster mushroom was affected by the different drying treatments (Table 2). The lowest moisture content was in sundried 8.40 gm/100gm followed by tray drying and freezer drying. Lower moisture content in sun dried samples may be due to relative humidity during the treatment. The carbohydrate and energy content were maximum in T1 (sundried) treatment 66.15 gm/100gm and 333.02 Kocal/100gm respectively. However, the protein content was maximum in T4 i.e. hot air oven drying treatment. The overall protein content of the oyster mushrooms in present study was lower than estimated by Bashir et al (2020) maximum crude protein in freeze dried oyster mushroom. Bülent and Mehmet (2020) studied the effect of different drying treatment (*viz.* oven drying, vacuum drying, solar drying, and freeze-drying) on the Keme mushroom (*Terfezia boudieri Chatin*) and found significant difference in ash and water activity of the mushrooms with non-significant difference between the moisture content of the dried mushrooms.

Mineral content in oyster mushroom powder dried: The calcium, sodium, potassium and magnesium were also analysed to understand the effect of drying treatments on respective mineral content in oyster mushroom (Table 3). The oyster mushrooms were had higher potassium content and ranged between 1439.67 and 1710.33 mg/100gm. The maximum calcium, sodium and magnesium were in T4 (hot air drying) (4.04, 12.02, 16.10 mg/100 gm, respectively. However, contrary results were recorded by Bashir et al (2020) and observed highest minerals in freeze dried oyster mushroom and recorded calcium, magnesium, potassium content of 16.12 and 2309.01 mg/100 g, respectively. Least mineral content was recorded in sun dried oyster mushrooms.

Vitamin-D_2 content in oyster mushroom powder: The highest vitamin D2 was noted in T1 (304.67 µg/100g) followed by T4 and T3 (Table 3). A study conducted by Ibrahim and co-workers (2022) on the exposure of oyster

Table 1. Functional properties in drying treatments of oyster mushroom (Mean ±SD)

Treatment	Oil binding capacity (g/gm)	Hydration capacity (g/gm)	TSS (°B)	Total sugars (%)	Non-reducing sugars (%)	Reducing sugars (%)
T_1	2.40 ± 0.006	3.14 ± 0.129	3.10 ± 0.020	6.39 ± 0.200	2.99 ± 0.214	3.40 ± 0.049
T_2	2.46 ± 0.012	4.02 ±0.050	3.35 ± 0.032	9.14 ± 0.079	4.81 ± 0.038	4.33 ± 0.080
T_3	2.45 ± 0.006	3.85 ± 0.137	3.26 ± 0.012	8.03 ± 0.114	4.01 ± 0.162	4.02 ± 0.050
T_4	2.47 ± 0.012	4.36 ± 0.090	3.40 ± 0.026	10.04±0.164	5.60 ± 0.113	4.80 ± 0.055
T_5	2.43 ± 0.006	3.55 ± 0.058	3.20 ± 0.038	7.09 ± 0.104	3.34 ± 0.087	3.75 ± 0.076
CD (p=0.05)	0.029	0.255	0.098	0.472	0.490	0.196

Table 2. Mean proximate composition in drying treatment of oyster mushroom (per 100gm) (Mean ±SD)

Treatment	Moisture (gm)	Crude protein (gm)	Crude fat (gm)	Crude fibre (gm)	Total minerals (gm)	CHO (gm)	Energy (Kcal)
T_1	8.40 ± 0.066	14.40 ± 0.067	1.20 ± 0.098	13.40 ± 0.145	4.85 ± 0.044	66.15 ± 0.226	333.02 ± 0.226
T_2	10.00 ± 0.076	16.42 ± 0.113	1.95 ± 0.023	15.39 ± 0.110	6.03 ± 0.058	60.21 ± 0.206	324.07 ± 0.206
T_3	9.72 ± 0.085	16.03 ± 0.044	1.68 ± 0.088	14.67 ± 0.104	5.86 ± 0.049	61.76 ± 0.174	326.26 ± 0.174
T_4	10.21 ± 0.038	17.10 ± 0.052	2.30 ± 0.056	16.40 ± 0.131	6.90 ± 0.099	57.30 ± 0.173	318.30 ± 0.173
T_5	8.88 ± 0.049	15.62 ± 0.095	1.34 ± 0.053	13.75 ± 0.153	5.48 ± 0.041	63.82 ± 0.232	329.82 ± 0.232
CD (p=0.05)	0.226	0.228	0.224	0.380	0.204	0.535	1.415

Table 3. Mean mineral content in drying treatments of oyster mushroom (per 100 gm) (Mean ±SD)

Treatment	Calcium (mg)	Sodium (mg)	Potassium (mg)	Magnesium (mg)	Vitamin-D_2 (µg)
T_1	3.41 ± 0.011	9.05 ± 0.080	1439.67 ± 0.055	13.40 ± 0.064	304.67 ± 22.696
T_2	3.93 ± 0.030	11.63 ± 0.107	1642.00 ± 0.059	15.89 ± 0.029	216.67 ± 17.638
T_3	3.78 ± 0.045	10.47 ± 0.138	1603.33 ± 0.044	15.57 ± 0.402	263.33 ± 12.019
T_4	4.04 ± 0.067	12.02 ± 0.102	1710.33 ± 0.049	16.10 ± 0.150	276.67 ± 21.858
T_5	3.59 ± 0.014	9.61 ± 0.143	1561.67 ± 0.164	14.26 ± 0.079	196.67 ± 24.037
CD (p=0.05)	0.114	0.317	22.780	0.596	65.198

Table 4. Effect of on organoleptic parameters in drying treatments of oyster mushroom

Treatment	Taste	Flavour	Aroma	Colour	Overall acceptability
T_1	4.88	5.00	4.67	5.00	5.00
T_2	6.33	8.00	7.67	8.00	7.00
T_3	6.00	7.33	7.00	7.33	6.00
T_4	7.33	9.00	8.33	9.00	8.67
T_5	5.67	6.00	5.33	6.33	5.67
CD (p=0.05)	2.242	3.243	3.333	2.855	2.595

mushroom to sunlight for 60 min before drying and found that the vitamin D2 content was increased by 158 per cent. However, the contradictory results were obtained by Simon et al (2011) in button mushrooms (*Agaricus bisporus*).

Organoleptic evaluation of oyster mushroom powder dried by different drying methods: The maximum taste, flavour, aroma, colour and overall acceptability score (7.33, 9.00, 8.33, 9.00 and 8.67) was recorded in treatment T_4 (hot air drying) and was best treatment among all drying treatments, whereas the minimum taste, flavour, aroma, colour, texture and overall acceptability score was recorded in treatment T_1(Sun drying).

CONCLUSION

The different drying treatments viz., sun drying, vacuum drying, freeze drying, hot air drying and tray drying were significantly influenced the physico-chemical properties and nutritional composition of oyster mushroom. The Hot air drying, was significantly superior among all drying treatments and gave the maximum biochemical properties, mineral components and physico-chemical properties, whereas the minimum observations were recorded in Sun drying.

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Evaluation of Genotypes against Bacterial Blight, Anthracnose Leaf Spot and Tobacco Streak Virus Diseases in Cotton

A. Vijaya Bhaskar

Plant Pathology, Agricultural Research Station, Karimnagar-505 007, India
E-mail: apvijayabhaskar@gmail.com

Abstract: The 54 cotton germplasms/hybrids/varieties and 13 Bt cotton hybrids with a check were screened against to anthracnose leaf spot, bacterial blight and tobacco streak virus diseases during *Kharif*-2017 at RARS, Warangal Telangana State. The thirteen entries viz., H-1492, DS-28**,** Deltapine-66, CCH-3114, CPD-731, ARB-8815, Hartsvilly, ADB-39, CPT-571, CPD-7575, CPD-812, TCH-1716 and NDLH-1967 were resistant to bacterial blight disease, three entries namely; Bikanerinerma, WGCV-26 and CPD 731-1 to anthracnose leaf spot disease and ARB-8815 was showed immune reaction to tobacco streak virus disease. Out of 13 Bt cotton hybrids screened against bacterial blight disease, five entries namely; Akira, Ashirwad, Moneymaker, RCH-839 and Superb were resistant to bacterial blight disease.

Keywords: Cotton germplasms, Bt Cotton, Bacterial blight, Anthracnose leaf spot, Tobacco streak virus diseases

Cotton crop is affected by fungal, bacterial and viral diseases. Among fungal diseases, Anthracnose leaf spot is an important disease which results the lower yields. In India, foliar diseases estimated to cause yield loss up to 20 to 30 per cent (Mayee and Mukewar 2007). Bacterial blight of cotton caused by *Xanthomonas axonopodis pv malvacearum* (Smith) is an important disease in Andhra Pradesh causing economic losses to the tune of 22.0 to 36.3 per cent (Bhattiprolu 2013 and 2018). Environmental conditions influence disease in cotton (Kumar et al 2018). Hence, it is imperative to identify resistant genotypes so as to utilize in breeding programs to evolve resistant varieties/hybrids. Resistant cultivars are compatible with all other tactics, contribute stability and offer advantage to integrated disease management system. Identification of sources of resistance facilitates to evolve resistant genotypes/varieties/hybrids, which in turn will be useful to the farming community in reducing the disease damage and fungicide consumption.

MATERIAL AND METHODS

Screening of the genotypes against the Bacterial blight, Anthracnose leaf spot and Tobacco streak virus diseases: 54 cotton germplasms/ hybrids/varieties were screened with LRA 5166 check and 13 Bt cotton hybrids were screened against to anthracnose, bacterial blight and tobacco streak virus diseases in under field conditions to identify the source of resistance in cotton at RARS, Warangal during *kharif* 2017. Each genotype was planted in two rows of 10 meter length with row spacing of 90 cm and the distance between plants was 60cm. The experiment was in randomized block design with two replications. Susceptible checks, LRA 5166 and RCH-629 were included after every 5 test rows for comparison in non Bt germplasms and Bt cotton respectively. For recording disease intensity, standard disease scale was adopted (Table 1).

Disease severity/PDI was assessed with 0-4 scale/grade as per the standard evaluation system followed in All India

Table 1. Scale adopted for cotton bacterial blight disease, anthracnose leaf spot and tobacco streak virus disease

Scale	Grade	Percent leaf area infected bacterial blight disease	Percent leaf area infected anthracnose leaf spot disease	Percent disease incidence of tobacco streak virus disease
0	Immune	Completely free from disease	Completely free from disease	Completely free from disease
1	Resistant	Spots few scattered upto 5%	Leaf area covered upto 5%	upper leaves showing chlorosis or necrosis from 0.1 to 5.0 %
2	Moderately resistant	Leaf area covered from 6 to 10%	Leaf area coveredfrom 6 to 20 %	Moderate square drying and few branches affected from 5.1 to 10.0 %
3	Moderately susceptible	Leaf area covered from 11 to 20%	Leaf area coveredfrom 21 to 40%	Severe drying of squares and more branches affected from 10.1 to 20.0 %
4	Susceptible	Leaf area covered >20%	Leaf area covered >40 %	Severe stunting inclusive of above symptoms > 20.0 %

Co-ordinate Research Project on Cotton. It was expressed in percent Disease Index (PDI). Disease score was recorded on ten randomly selected plants in each entry on 0-4 scale (Sheo Raj1988).

Data collected: Disease observations were noted from 10 tagged plants at random from each entry. Three leaves at bottom, four in the middle and three at the top of each plant thus total 10 leaves were collected from tagged plant. Disease scored at peak intensity was observed by using disease grades. Depending on the scores collected, % disease intensity (PDI) was calculated by using the formula by Wheeler (1969).

$$\text{PDI} = \frac{[\text{Sum of all the numerical ratings}]}{[\text{Total number of leaves scored} \times \text{Maximum disease grade}]} \times 100$$

In case of Tobacco Streak Virus (TSV) percent disease incidence was recorded as follows

$$\text{Percent disease incidence} = \frac{[\text{Number of infected plants}]}{[\text{Total number of plants}]} \times 100$$

RESULTS AND DISCUSSION

Evaluation against bacterial blight disease: On screening of 54 cotton germplasm against bacterial blight disease, thirteen entries were resistant to bacterial blight disease (Table 1a). The 13 Bt cotton hybrids against bacterial blight disease, five entriesAkira, Ashirwad, Moneymaker, Rch-839 and Superb resistant to bacterial blight disease (Table 2a). Hosagoudar et al (2008) reported, twenty seven varieties were immune to bacterial blight disease. Guravareddy et al (2015), observed, Pratheek BG-II and Bigboss BG-I resistant to bacterial blight disease. Screened 221 cultivated genotypes for resistance against bacterial leaf blight disease, 80 genotypes showed immune reaction, 69 genotypes were resistant and 13 genotypes were moderately resistant bacterial blight disease (Patole et al 2016).

Against bacterial blight disease, Prashant et al (2017) found that 25 entries were disease free, 6 entries were resistant and 6 entries were moderately resistant, Bhattiprolu et al 2017 noticed that 4 Bt entries had moderately susceptible reaction, Patel et al 2016 and 2019 observed that 7 genotypes were disease free, GBav-123 was resistant and Abdul Rashid et al 2020 found that 8 entries were immune and 4 entries were moderately resistant .

Evaluation of anthracnose leaf spot disease: Out of 54 entries screened, three entries were found resistant to Anthracnose leaf spot (Table 1b). On screening against alternaria leaf blight disease, Hosagoudar et al (2008) found that JKCDH 501 was moderately resistant, Chattannavar et al 2009 found that 9 test entries were resistant, Gurava

Table 1a. Screening of germplasms against bacterial blight disease

Germplasms	% Bacterial blight leaf area infection (PDI)	Scale (0-4)	Reaction
Akala -629	20	3	MS
H-1492	4	1	R
Bikanerinerma	8	2	MR
G-67	9	2	MR
Delfos	8	2	MR
Deltapine -66	4	1	R
CCH-3114	3	1	R
CH-156	7	2	MR
CCH-1831	6.5	2	MR
CPD-814	6	2	MR
CPD-731	5	1	R
RAH-902	12.5	3	MS
Anjali	15	3	MS
AV1SP	25	4	S
ARB-8815	4	1	R
GSHV-97/59	15	3	MS
GSHV-97/13	15	3	MS
Hartsvilly	5	1	R
ADB-39	3	1	R
AV-3469	20	3	MS
GJHV-97/29	15	3	MR
HS-271	10	2	MR
BS-30	8.9	2	MR
GJHV-502	6.0	2	MR
CPT-571	4	1	R
CPD-7575	4.5	1	R
CPD-812	3	1	R
TCH-1716	4.5	1	R
Akala-1512	10	2	MR
NA-777	25	4	S
NA-1568	17	3	MS
WGCV-29	15	3	MS
WGCV-43	15	3	MS
WGCV-26	10	2	MR
CPD-731-1	9.34	2	MR
CNH-1025	9.60	2	MR
CSH-3167	15	3	MS
GSHV-160	10	2	MR
RS-2569	25	4	S
RS-2557	10	2	MR
WGCV-116	15	3	MS
LH-2153	20	3	MS
DS-28	4.5	1	R
JK-2602	7.8	2	MR
JK-344	15	3	MS
PRS-02	14.60	3	MS
WGCV-135	12	3	MS
JK-5	10	2	MS
L-620	10	2	MR
NDLH-1967	3	1	R
RAH-221	10	2	MR
WGCV-92	15	3	MR
WGCV-115	25	4	S
LRA-5166 (SC)	54	4	S

R-Resistant, MR-moderately resistant, MS-Moderately susceptible and S-Susceptible

Table1b. Screening of cotton germplasms against anthracnose leaf spot and tobacco streak virus diseases

Germplasms	Anthracnose leaf spot (PDI)	Scale (0-4)	Reaction	Tobacco streak virus disease scale (0-4)	PDI	Reaction
Akala -629	25	3	MS	1	0.9	R
H-1492	20	2	MR	1	1.2	R
Bikanerinerma	2.6	1	R	1	2.0	R
G-67	15	2	MR	1	1.5	R
Delfos	18	2	MR	1	2.5	R
Deltapine -66	20	2	MR	1	3.0	R
CCH-3114	22	3	MS	1	3.2	R
CH-156	16	2	MR	1	2.6	R
CCH-1831	19	2	MR	1	2.9	R
CPD-814	14	2	MR	1	3.2	R
CPD-731	20	2	MR	1	4.0	R
RAH-902	17	2	MR	2	8.2	MR
Anjali	25	3	MS	1	3.4	R
AV1SP	20	2	MR	1	4.0	R
ARB-8815	18	2	MR	0	0	I
GSHV-97/59	26	3	MS	1	2.1	R
GSHV-97/13	22	3	MS	1	2.6	R
Hartsvilly	23	3	MS	1	3.0	R
ADB-39	18	2	MR	1	2.4	R
AV-3469	20	2	MR	2	9.0	MR
GJHV-97/29	17	2	MR	1	1.2	R
HS-271	22	3	MS	1	2.8	R
BS-30	18	2	MR	1	3.0	R
GJHV-502	15	2	MR	1	3.4	R
CPT-571	22	3	MS	1	4.0	R
CPD-7575	20	2	MR	1	4.6	R
CPD-812	14	2	MR	1	3.2	R
TCH-1716	12	2	MR	3	15.2	MS
Akala-1512	15	2	MR	3	18.4	MS
NA-777	26	3	MS	1	1.2	R
NA-1568	34	3	MS	1	3.4	R
WGCV-29	20	2	MR	1	3.0	R
WGCV-43	20	2	MR	1	4.3	R
WGCV-26	2.5	1	R	1	2.8	R
CPD-731-1	5.0	1	R	1	3.0	R
CNH-1025	20	2	MR	2	7.6	MR
CSH-3167	26	3	MS	1	2.2	R
GSHV-160	18	2	MR	1	3.4	R
RS-2569	28	3	MS	3	18.6	MS
RS-2557	15	2	MR	1	2.0	R
WGCV-116	24	3	MS	1	3.2	R
LH-2153	16	2	MR	1	4.5	R
DS-28	23	3	MS	2	7.8	MR
JK-2602	18	2	MR	1	1.2	R
JK-344	35	3	MS	1	2.0	R
PRS-02	17	2	MR	1	3.2	R
WGCV-135	21	3	MS	1	4.0	R
JK-5	18	2	MR	1	3.8	R
L-620	27	3	MS	1	2.6	R
NDLH-1967	36	3	MS	1	1.8	R
RAH-221	20	2	MR	1	2.0	R
WGCV-92	48	4	S	1	2.2	R
WGCV-115	24	3	MS	1	3.4	R
LRA-5166 (SC)	50	4	S	4	25.6	S

R-Resistant, MR-moderately resistant, MS-Moderately susceptible and S-Susceptible

reddy et al 2015 found that Ganesh BG-II was resistant and Gawande et al 2016 noticed that one was exotic, 10 were indigenous and 19 were wild genotypes.

According to Hosagoudar et al (2008) Eighty six non-Bt and nine Bt cotton hybrids/ varieties/genotypes were screened against alternaria leaf blight disease, one was moderately resistant (JKCDH 501); 196 cotton hybrids/cultivars/genotypes were screened for resistance to alternaria blight disease, 9 test entries were found resistant (Chattannavar et al 2009); out of fifty Bt cotton hybrids, Ganesh BG-II was found resistant (Gurava reddy et al 2015); Exotic (01); 10- Indigenous and 19-Wild genotypes were identified as highly resistant (Gawande et al 2016) to the alternaria leaf blight disease.

Table 2a. Screening of Bt cotton hybrids against bacterial blight disease

Hybrids	% Bacterial blight leaf area infection (PDI)	Scale (0-4)	Reaction
Akira	2.4	1	R
Ashirwad	2.6	1	R
Deta Pine 912	20	3	MS
Khazana	15	3	MS
Money Maker	4.9	1	R
Neo	15	3	MS
Punnami 9	20	3	MS
Rch 797	25	4	S
Rch 839	3.8	1	R
Superb	4.5	1	R
Suvarna	15	3	MS
Ujwal	20	3	MS
Rch 929 (Sc)	50	4	S

R-Resistant, MR-moderately resistant, MS-Moderately susceptible and S-Susceptible

According to Bhattiprolu et al 2017 noticed that RCH-530 BG-II was resistant and 38 were moderately resistant to helminthosporium leaf spot, 28 hybrids showed moderately resistant reaction to myrothecium leaf spot, Tulasi-118 BG-II was free and seven hybrids Bt were found resistant reaction to cercospora leaf spot disease. Two glandless cotton genotypes and three commercial cultivars were found more resistance to alternaria leaf spot disease (Yi Zhu et al 2017); Twenty-one genotypes showed resistant reaction (Rajesha et al 2021); one hundred and forty three Bt. cotton hybrids, two hybrids viz., Tulasi-144 BG-II (3.75 PDI) and U5-SS-33 BG-II (4.38 PDI) were recorded resistant (Durga Prasad et al 2017); Thirteen entries were showed resistant reaction (Chaudhari et al 2022) to alternaria leaf spot disease.

Evaluation of tobacco streak virus disease: Out of evaluated 54 entries, one entry was noticed immune response (scale 0), 45 entries were resistant (scale 1) and four entries were noticed scale 2 (moderately resistant) to tobacco streak virus disease (Table 1 b).

On screening of 13 Bt Cotton hybrids, seven entries showed rating scale 1 (resistant) to tobacco streak virus disease (Table 2b).

Three hybrids were immune and twenty two entries were resistant to tobacco streak virus disease (Guravareddy et al 2015), Tobacco streak virus disease incidence was noticed upto a maximum of 50 per cent in hybrids, more than the incidence in varieties under natural condition in different cotton growing areas of Tamil Nadu (Rageshwari et al 2016),

Table 2b. Screening of Bt cotton hybrids against anthracnose leaf spot and tobacco streak virus diseases

Hybrids	Anthracnose leaf spot (PDI)	Scale (0-4)	Reaction	Tobacco streak virus disease scale (0-4)	PDI	Reaction
Akira	20	2	MR	1	2.1	R
Ashirwad	25	3	MS	2	8.4	MR
Deta Pine 912	32	3	MS	1	2.5	R
Khazana	55	4	S	2	9.0	MR
Money Maker	25	3	MS	3	18.6	MS
Neo	38	3	MS	1	2.6	R
Punnami 9	46	4	S	1	3.8	R
Rch 797	58	4	S	3	20	MS
Rch 839	36	3	MS	2	9.2	MR
Superb	25	3	MS	1	4.0	R
Suvarna	46	4	S	1	3.6	R
Ujwal	40	4	S	1	3.9	R
Rch 929	60	4	S	4	23.4	S

R-Resistant, MR-moderately resistant, MS-Moderately susceptible and S-Susceptible

Telangana had the highest incidence of tobacco streak virus (51.11 PDI-hybrid RCH 659) among the surveyed locations including Tamil Nadu, Andhra Pradesh, Telangana and Maharashtra states of India (Vinodkumar et a l2017), Valarmathi et al 2020 found that maximum per cent tobacco streak virus disease incidence was observed 26.6% in ICB 71 and 20.5% in CCB 129 and Per cent disease incidence was maximum in SXP (35.8 per cent), followed by Suvin (32.5%) and ICB-25 (26.6%) with disease grade of 3.

CONCLUSIONS

Out of 54 cotton germplasms, 13 entries were found resistant to bacterial blight disease, 3 entries (Bikanerinerma, WGCV-26 and CPD 731-1) were found resistant to anthracnose leaf spot disease and ARB-8815 was noticed immune reaction to tobacco streak virus disease.ARB-8815 was found to be multiple disease resistance to bacterial blight and tobacco streak virus diseases. Out of 13 Bt cotton hybrids, Akira was found moderately resistant to anthracnose leaf spot disease; Akira and Superb hybrids were found multiple disease resistant to bacterial blight and tobacco streak virus diseases.

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Study of Morphometric and Meristic Characters, Length-Weight Relationship and Condition Factor of *Schizothorax esocinus* from Kashmir Valley

Merlin Mary Philip, Tasaduq H. Shah, Asifa Wali and Syed Talia Mushtaq

Division of Fisheries Resource Management, Faculty of Fisheries
SKUAST-Kashmir, Rangil, Ganderbal, Kashmir-190 006, India
E-mail: merlinmaryp17@gmail.com

Abstract: The present study was conducted to analyse various morphological characters along with length-weight relationship (LWR) and condition factor of *Schizothorax esocinus* from Manasbal Lake, Kashmir during its breeding season. Fourteen morphometric characters were analysed to conclude correlation between the characters from analysis of 'R' values, which ranged from 0.482-0.964 and 0.335-0.384 for males and 0.380-0.922 and 0.351-0.578 for females (for total length and head length respectively). There was no significant difference in the number of fin rays except for pectoral fin rays between males and females. The LWR for males was established as Log W = -1.255 + 2.511 Log L and for females as Log W = -0.914 + 2.299 Log L. Condition factor was1.02 and 1.07 for males and females.

Keywords: *Schizothorax esocinus,* Snow trout, Morphometry, Meristics, Length-weight relationship, Condition factor

Jammu and Kashmir, considered as the 'Snow trout place' or the 'Snow barbel place' lies between 32°17'N to 36°58' N latitudes and 73°26 E' to 80°30' E longitudes and is home to several indigenous and exotic cold water fish species of families Cyprinidae, Salmonidae, Cobitidae, Sisoridae, Siluridae, Poecilidae etc. (Raina 2002). The valley of Kashmir has several rivers, their tributaries, lakes and springs which influence the social and economic spheres of life of the people of the valley by contributing to fisheries as well as tourism. Schizothoracids, which include *Schizothorax* and *Schizothoraichthys* species, along with other cyprinid fishes form an inevitable part of subsistence and commercial fisheries (Singh et al 2014). Schizothoracids which migrated from Central Asiatic water sheds got isolated in the Kashmir waters and became endemic to the region. But the anthropogenic activities are threatening their existence due to pollution, eutrophication and exotic species introduction like common carp and brown trout (Singh and Lakra 2008, Kausar et al 2017). Singh and Lakra (2008) have listed them as indeterminate fish which need to be evaluated for determining their conservation status. *Schizothorax esocinus* belongs to family Cyprinidae and sub-family *Schizothoracinae. S. esocinus* can be a bioindicator of aquatic pollution and are benthopelagic (Shafi et al 2021a).

Morphometric and meristic characters are considered authentic for species identification and are known as morphological systematics. Morphometrics is the study of quantitative analysis of form which includes the measurement of length between physical features which helps to identify differences between various fish populations and describe the shape of each of them (Pollar et al 2007). In populations and within species of fish, there are greater differences in the morphological characters compared to any other vertebrate. Changes can occur in the morphological characters in response to the changing environment and various environmental factors like food availability, temperature, etc. which bring about changes in morphometrics as well and they adjust to these changes by adapting for better survival (Nacua et al 2010). In a population that is geographically isolated as in case of the Schizothoracids of Kashmir valley, it is important to study the populations for arriving at conclusions regarding the morphological and morphometric adaptations, genetic drift etc.

IMPORTANCE AND OBJECTIVES

This study helps to understand the changes in morphometric and meristic characters in the species, which can be an important aspect of evolution and adaptation happening in the landlocked region. Condition factor is a means to understand the state of well-being of the species in their natural systems which becomes important for its survival. Conclusions of the study can be useful in requisite management measures for *S. esocinus*. The study aims to evaluate the data to produce results useful for the same.

MATERIAL AND METHODS

Thirty fish specimens of *S. esocinus* were collected from commercial catches of Manasbal lake in May-June, 2022. Manasbal Lake is located between 34° 14' 60.00" N latitude and 74° 39' 59.99" E longitude in the district of Ganderbal, Kashmir. The fish were brought to Division of Fisheries Resource Management, Faculty of Fisheries, SKUAST-K in ice boxes for analysis. The size range of the specimens was 275 grams to 569 grams in weight and 274 mm to 376 mm in total length, of which 17 were males and 13 were females.

Morphometric and meristic characters: The morphometric measurements were taken from fresh samples from the left side of the samples. 14 morphometric characters were measured (Fig. 2). Meristic characters studied were counts of fin rays and spine of dorsal fin, pectoral fin, pelvic fin, anal fin and caudal fin. Meristic counts were made after setting up against incoming light using a needle and small pins for easy counting. The generated data were analyzed statistically to estimate the correlation between various parameters using Microsoft Excel 16.0 and Past 4.03. The morphometric measurements and meristic counts were made based on the definitions according to Srivastava (1988), Yadav (2007), Sandhu (2007) and Khillare (2010).

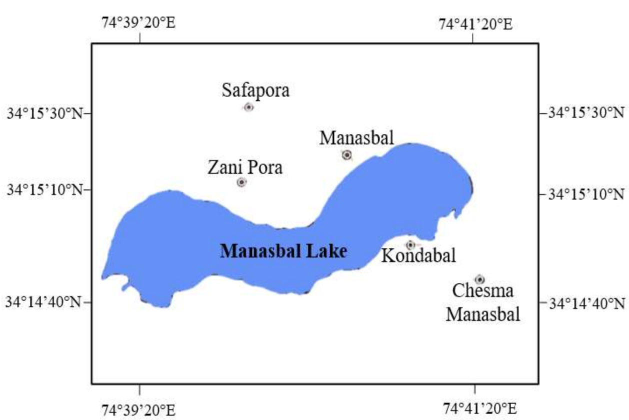


Fig. 1. Map of Manasbal Lake

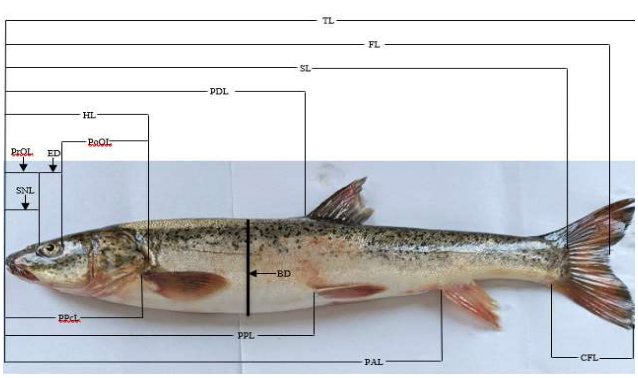


Fig. 2. Morphometric measurements of *S. esocinus*

TL- Total length; SL- Standard length; FL- Fork length; PDL- Pre-dorsal length; PAL- Pre-anal length; PPL- Pre-pelvic length; PPcL- Pre-pectoral length; ED- Eye diameter; BD- Body depth; HL- Head length; PoOL- Post orbital length; PrOL- Pre orbital length; SNL- Snout length; CFL- Caudal fin length

Length-Weight relationship: Length-Weight relationship was established by using the allometric formula (Le Cren, 1951).

$$W = a L^b$$

Were,

W = Weight of the fish in grams

L = Total length of the fish in centimeters

a = Exponent describing the rate of change of weight with length (= the intercept of the regression line on the Y axis)

b = The regression co-efficient or the slope (also referred to as the Allometric coefficient).

The logarithmic conversion of the above equation was used to establish a linear relationship, which is given as follows:

$$\text{Log } W = \text{Log } a + b \text{ Log } L$$

Where 'W' is the weight of fish in grams, 'a' is the constant, 'b' is the regression co-efficient and 'L' is the total length of fish in centimeters.

Condition factor: The Condition factor was calculated as (Fulton 1904):

$$K = \frac{W}{L^3} \times 100$$

Where;

W = Weight of the fish in grams

L = The total length of the fish in centimeters

RESULTS AND DISCUSSION

Morphometric and meristic characters: Least coefficient of variation was obtained for eye diameter (5.55 and 6.92%) and highest for snout length (13.72 and 16.63%) in both males and females. Standard length shows high correlation with total length in both the males (0.964) and females (0.922) similar to the observations of Shafi et al (2021a) and Shafi et al (2021b). Fork length is least correlated to total length in males (0.483) but it is highly related in females (0.899). Caudal fin length has least correlation to total length in both the sexes (0.482 and 0.380) as reported by Arafat and Bakhtiyar (2020) in *S. labiatus*. Eye diameter has shown a very weak and negative correlation to head length in both males and females, consistent with conclusions by Krishnan and Tarana (2010) in *S. richardsonii* from Uttarkashi. The standard length showed highest correlation (r = 0.986) followed by pre-anal length (r = 0.981), which is similar to the results in *Oncorhynchus mykiss* studied by Wali et al (2018) and *S. esocinus* males in the current study. The morphometric characters are highly correlated and the R values justify their proportionate increase. The lesser correlation values show smaller changes in the dependent parameters while the fish grows in total length. Females showed a greater number of characters which possess higher correlation than males. However, males showed a higher value of R for the characters similar to reports by Mohan and Williams (2018) in *Oxyurichthys tentacularis* from Ashtamudi Lake. The Kruskal Wallis test conducted for the morphometric parameters of males and females showed a significant difference between the sample medians and proved that there was no significant difference in the number of fin rays except for pectoral fin rays between males and females which is in agreement to observations of Shafi et al (2021a) and Shafi et al (2021b) and likewise for the fin formula given as D, I + 5-10, P, I + 7-11, C, I + 15-23, A, I + 3-7. Shafi et al (2021a) and Khan et al (2021) concluded that the number of dorsal fin rays and caudal fin rays were not significantly different and that variance existed in other characters for specimens from different sites. Any difference in morphometric and meristic traits between males and females, or between same species from different sites and different time period can be considered as a mode of adaptation suitable for the environment (Table 1).

Length-weight relationship: Females showed a higher correlation between length and weight, while the 'b' value (growth co-efficient) was higher in males than females. The relationships for males, females and combined were established as, Log W = -1.255 + 2.511 Log L; Log W = -0.914 + 2.299 Log L and Log W = -1.073 + 2.397 Log L respectively (Fig. 7A, B, Fig. 8). Reshi and Ahmed (2020) reported that the value of 'b' in LWR was always greater than 3 through various seasons. Jobling (2002) and Froese (2006) observed that 'b' value lower than 2.5 shows an over-proportional increase in length than weight, which is clearly shown by the females of *Churruh.* The males are showing values less than 3 and therefore, becomes lean with increase in length. Wani et al (2020) in *S. niger* and Syed et al (2020) in *Cyprinus carpio* var. *communis* observed males showed higher 'b' values compared to females, and therefore, better growth. Syed et al (2020) observed a similar trend in *Cyprinus carpio* var. *communis* from Manasbal Lake. Negative allometric growth was shown by *S. curvifrons* and *S. labiatus* as reported by Qadri et al (2017) and Farooq et al (2017) respectively. Jan and Ahmed (2016) observe that *S. plagiostomus* males showed negative allometric growth (b < 3) throughout the year and females had a higher 'b' value. Isometric growth was reported in farmed female rainbow trout by Shah et al (2011) and in *Oncorhynchus mykiss* by Wali et al (2018) and Shah et al (2013). Rani et al (2018) predicted higher physiological stress in the natural habitat for *Schizothorax niger* (b =2.572044) compared to *S. richardsonii* (b =3.027319), suggesting a similar situation for *S. esocinus* in the present case. The low values of 'b' in *S. esocinus* can be contributed by the reproductive and environmental stress, food

Table 1. Morphometric characters of *S. esocinus*

Statistical estimates	Males			Females		
	Range (mm)		Mean (mm)	Range (mm)		Mean (mm)
	Minimum	Maximum		Minimum	Maximum	
Total length (TL)	273.7	374.4	325.49	282.78	376.42	324.34
Standard length (SL)	239.74	323.39	279.09	250.27	324.27	283.32
Fork length (FL)	261.19	381.92	307.65	269.3	349.45	303.39
Pre-Dorsal length (PDL)	121.24	162.7	142.37	122.54	158.53	142.32
Pre-Anal length (PAL)	183.27	250.76	216.32	193.04	271.31	224.50
Pre-Pelvic length (PPL)	128.02	179.33	151.06	127.28	174.96	150.9
Pre-Pectoral length (PPcL)	57.63	80.97	68.84	55.38	78.27	69.67
Eye diameter (ED)	10.25	12.49	11.07	10.24	12.95	10.86
Body depth (BD)	49.83	71.84	59.68	49.81	72.37	61.66
Head length (HL)	45.67	78.49	63.74	50.19	79.84	64.52
Post-Orbital length (PoOL)	18.61	27.33	22.74	25.36	43.92	35.27
Pre-Orbital length (PreOL)	26.77	42.14	35.92	17.17	25.93	22.47
Snout length (SNL)	16.5	26.4	21.44	14.23	24.79	20.65
Caudal fin length (CFL)	42.68	63.54	49.39	42.79	59.73	51.30

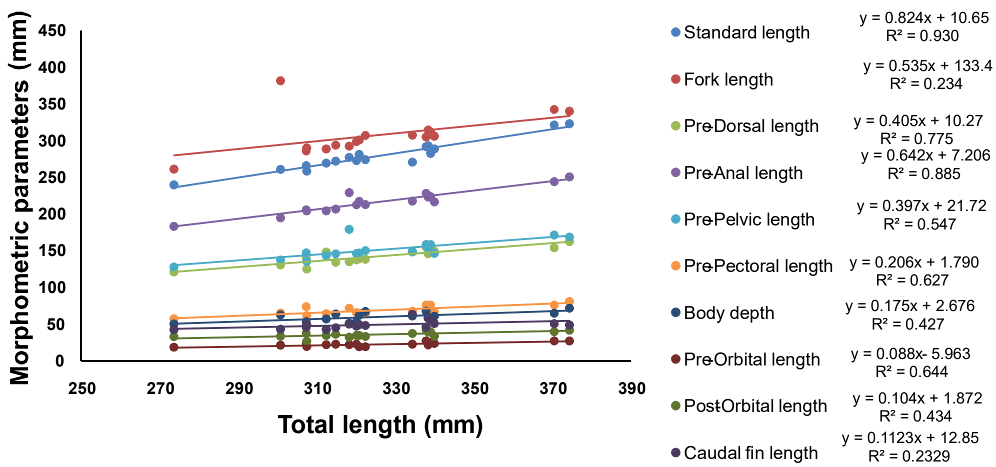


Fig. 3. Logarithmic relationship of different morphometric characters with total length in *S. esocinus* (Males)

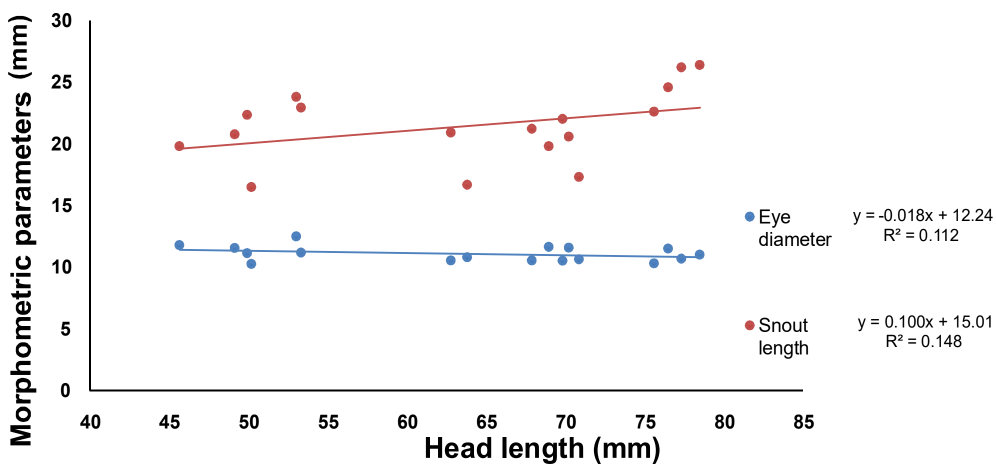


Fig. 4. Logarithmic relationship of eye diameter and snout length with head length in *S. esocinus* (Males)

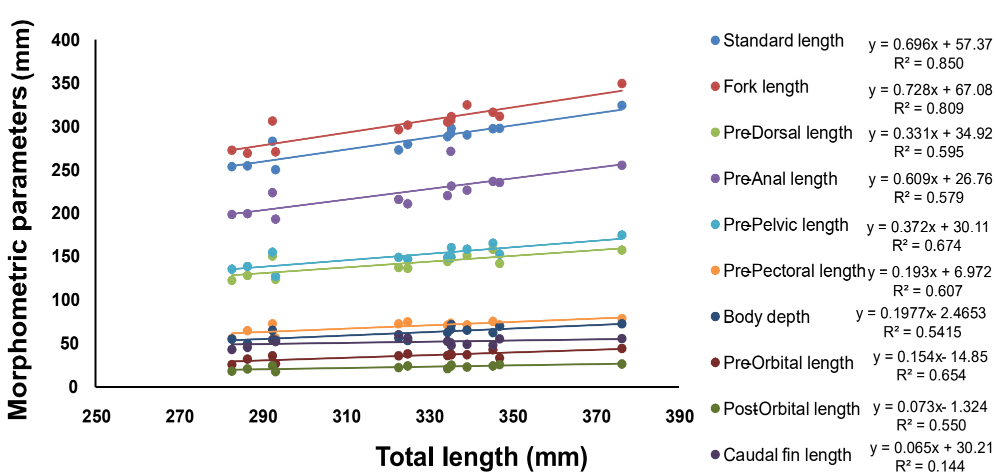
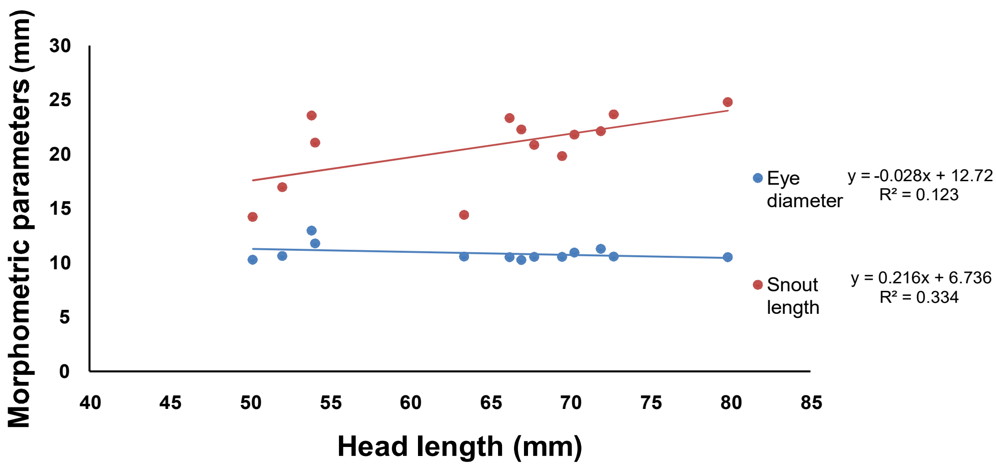


Fig. 5. Logarithmic relationship of different morphometric characters with total length in *S. esocinus* (Females)

availability, chemicals in the aquatic environment etc. A greater effect of these factors, especially the reproductive activity and stress in females might be the reason for even lower 'b' values.

Condition factor: The mean condition factor in males and female was 1.02 and 1and this confirms the readiness of the fish to spawn, since the period corresponded to the spawning season of the species. Reshi and Ahmed (2020) has reported highest value of K for *S. esocinus* in autumn, followed by summer and the lowest during spring and winter consistent present study. Since the low K coincided with high GSI values, spawning season was predicted during spring to summer. Shah et al (2011) reported excellent condition of farmed female rainbow trout in Kashmir from the mean K



FFig. 6. Logarithmic relationship of eye diameter and snout length with head length in *S. esocinus* (Females)

Table 2. Correlation between various morphometric traits of *S. esocinus*

Morphometric characters	Males				Females			
	Slope b	Intercept a	Y=a +bx	R (Correlation coefficient)	Slope b	Intercept a	Y=a +bx	R (Correlation coefficient)
Total length & Standard length	0.8247	10.653	y = 0.8247x + 10.653	0.964	0.6967	57.372	y = 0.6967x + 57.372	0.922
Total length & Fork length	0.5352	133.45	y = 0.5352x + 133.45	0.483	0.7286	67.087	y = 0.7286x + 67.087	0.899
Total length & Pre-Dorsal Length	0.4059	10.27	y = 0.4059x + 10.27	0.880	0.3311	34.925	y = 0.3311x + 34.925	0.771
Total length & pre-Anal length	0.6425	7.2067	y = 0.6425x + 7.2067	0.940	0.6097	26.766	y = 0.6097x + 26.766	0.761
Total length & Pre-Pelvic Length	0.3974	21.724	y = 0.3974x + 21.724	0.740	0.3727	30.111	y = 0.3727x + 30.111	0.821
Total length & Pre-Pectoral length	0.206	1.7901	y = 0.206x + 1.7901	0.791	0.1933	6.972	y = 0.1933x + 6.972	0.779
Total length & Body depth	0.1751	2.676	y = 0.1751x + 2.676	0.654	0.1977	2.4653	y = 0.1977x - 2.4653	0.735
Total length & post orbital length	0.1046	1.8727	y = 0.1046x + 1.8727	0.659	0.1546	14.858	y = 0.1546x - 14.858	0.809
Total length & Pre-orbital length	0.0882	5.9634	y = 0.0882x - 5.9634	0.802	0.0734	1.3242	y = 0.0734x - 1.3242	0.741
Total length & Caudal fin length	0.1123	12.85	y = 0.1123x + 12.85	0.482	0.065	30.211	y = 0.065x + 30.211	0.380
Head length & Snout length	0.1009	15.011	y = 0.1009x + 15.011	0.384	0.216	6.7364	y = 0.216x + 6.7364	0.578
Head length & Eye diameter	-0.0184	12.242	y = -0.0184x + 12.242	-0.335	-0.0287	12.72	y = -0.0287x + 12.72	-0.351

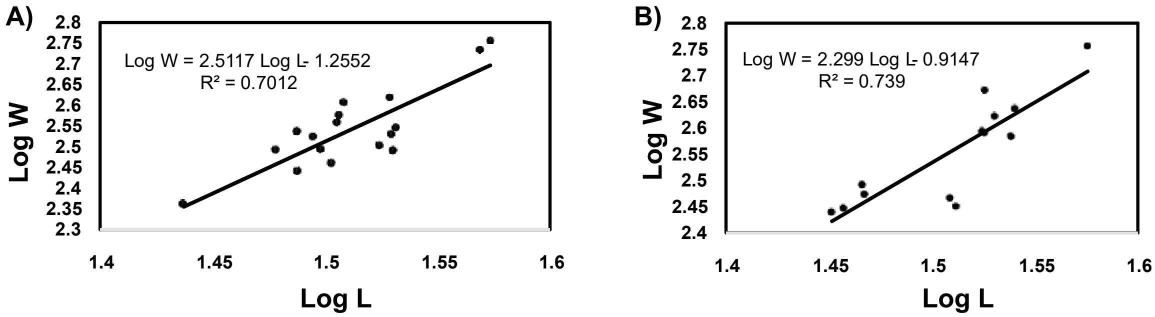


Fig. 7. Logarithmic relationship between length and weight in *S. esocinus*: **A)** Males **B)** Females

Table 3. Meristic characters of *S. esocinus*

Meristic characters	Males				Females			
	Range	Mean	Median	Standard deviation	Range	Mean	Median	Standard deviation
Dorsal fin rays	7-9	7.94	8	0.42	7-8	7.92	8	0.27
Pectoral fin rays	13-17	15.11	16	1.21	12-19	15.23	15	1.92
Pelvic fin rays	8-10	8.70	9	0.68	9-10	9.38	9	0.50
Anal fin rays	5-6	5.05	5	0.24	5	5	5	0
Caudal fin rays	18-22	20.29	20	1.10	19-21	19.61	19	0.76

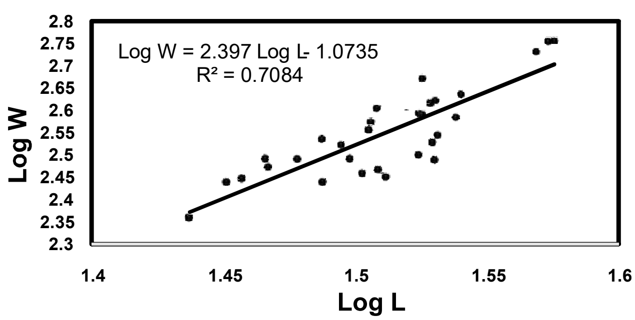


Fig. 8. Logarithmic relationship between length and weight in *S. esocinus* (Combined)

value of 1.15. Prevalence of conducive environment for *Oncorhynchus mykiss* in Dachigam stream of Kashmir was concluded from the K value near unity (K = 1.15) by Shah et al (2013). In *Schizothorax labiatus* in River Jhelum, Farooq et al (2017) observed that the condition of the fish ranged from excellent to poor. Compared to the above results the condition of *Churruh* is satisfactory from the mean K value, although lower 'b' values were obtained in LWR estimates. There would be effects of environment, breeding activity, food availability and less food intake during breeding season which may influence low K values in other species. Wali et al (2021) reported variation in monthly K values of *Oncorhynchus mykiss* from different sites, proving that variation in environment can effect changes in condition factor. Females showed higher K value than males of *Amblyceps apangi* as reported by Kachari et al (2017) from Arunachal Pradesh and by Syed et al (2020) in *Cyprinus carpio* var. *communis* from Manasbal Lake, Kashmir, which was observed in the current study as well.

CONCLUSION

The present study analyzed some morphological and biological characters of the indigenous snow trout *S. esocinus* of Kashmir valley which will provide the field of fisheries science with updated information on the same. This can be considered relevant and will help in proper management of the resource and analysing stock structure of this species. This becomes necessary considering the situations of its population being threatened by various environmental and climatic conditions, anthropogenic activities, alien species invasion and so on. Since this fish is endemic to the regions where it is found at present, it is imperative to implement scientific species-specific conservation and management measures to ensure its well-being. An improvement in the status of the fish in natural waters can help with better production and income for local fisher population.

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Impacts of Hydropower on Seasonal Rhythms of Diatoms in Indian Himalayan Region

Neetika Sharma and Prakash Nautiyal

Department of Zoology, H.N.B. Garhwal University, Srinagar Garhwal-246 174, India
E-mail: neetika185@gmail.com

***Abstract*:** The hydrology of river Alaknanda in the Indian Himalayan region having glacier at source varies due to magnitude of melt in different seasons. Power generation requirements cause abrupt perturbations in the discharge of serially impounded Alaknanda River. Diatom assemblages were recorded at eight stations within and outside hydroelectric project (HEP) area to study the seasonality in diatom assemblages during 2017-2018. The assemblages reflected the bare minimum of seasonality at each station viz. *Achnanthidium pyrenaicum-Achnanthidium minutissimum* during May and June of summer season at S3; *A. pyrenaicum - Cymbella laevis* during January and February of winter season at S4; late summer at S5 (*A. pyrenaicum-C. placentula* var. *euglypta*), S6 (*A. minutissimum-A. pyrenaicum*) and S8 (*A. pyrenaicum-A. minutissimum*). The assemblages showcased no seasonal consistency during the study period. These were inferred as perturbations caused by discharges held and released for power generation, suggesting the unstable nature of communities in the Alaknanda River ecosystem impacted by serial impoundments.

Keywords: Alaknanda, hydropower, Diatom assemblages, Seasonality, Indian Himalayan region

The Alaknanda is one of the two source rivers of the holy Ganga flowing in the State of Uttarakhand in Indian Himalayan region (IHR), and constitute the headwater ecosystem. The hydrology of the Alaknanda varies seasonally due to snow accumulation during winters, melting of glaciers in summer and surface run-off during monsoon which translates into lean flow during winter (November - February), low flow during summer (March - June) and high flow during monsoon (July to September ~ October). Other than monsoon floods the natural discharge crucial to the ecosystem is held back for hydropower generation which alters the hydrology or hydrodynamic parameters in rivers downstream of the power house (PH). It involves the release of peak flows downstream of the HEP, inducing abrupt fluctuations of discharge and physical parameters (e.g. water velocity, transparency) associated with it. Fluvial changes affect the river ecosystems. The construction of dams with a reservoir alters the domain of flowing water. They impose greater pressure on the aquatic systems in relation to longitudinal trends in species and, functional composition (Braatne et al 2010). Many studies have been conducted on the seasonality of diatoms in the past, though not with respect to HEP (Everest and Aslan 2016, Shaawiat and Hassan, 2017, Goldenberg Vilar et al 2018, Snell et al 2019 and Paches et al 2019).

Few studies have examined seasonality in producer communities impacted by hydroelectric projects viz. impact of a large hydroelectric dam in the river Colorado, USA (Peterson 1986); impact of barrages in the regulated section between Rishikesh and Haridwar of the river Ganga (Badoni et al 1999); impacts of small run-of-river dams in the Xiangxi river, China (Wu et al 2010); seasonal dynamics of phytoplankton due to water level fluctuations in a reservoir of south-eastern China (Li et al 2018); seasonality of benthic diatom assemblages in the Kiskore reservoir of the Great Hungarian plain (Kokai et al 2019) and effects of altered flow regimes in three Spanish river basins (Goldenberg-Vilar et al 2022). The findings by Singh and Parikh (2020) shed light on the ecological significance of endemic diatoms identified in urban ecosystems. Considering this, a study was conducted to investigate the seasonality of diatom assemblages in the river Alaknanda modified for hydropower generation.

MATERIAL AND METHODS

Study area: The study area extends from upstream Vishnuprayag hydroelectric project (VHEP; 30°40'37"N, 79°30'37"E) in upper stretch to downstream Srinagar hydroelectric project (SHEP) powerhouse (30°13'19"N, 78°40'54"E) in lower stretch. Eight sampling stations (S1 to S8) depending on the accessibility and which were directly influenced by these hydroelectric projects were selected for sampling (Fig. 1, Table 1). The riverscape in the study area comprised of steep to moderate slopes having dense *Cedrus* to open *Pinus* Forest with spread-out small human habitations from headwaters to mouth.

Rationale for selection of stations: The river in the study area was categorized into i) Area of Influence (AoI) of HEP extending from ca. 1 km upstream (u/s) of impounded section to power house (PH- the point where diverted discharge returns to the river) and ii) free flowing river sections (FFRS) extending from downstream (d/s) of PH to ca. 1 km u/s tail of impounded section. Hence, there were two HEP-AoI and two free flowing river sections, one between V-HEP-AoI and other downstream (d/s) of S-HEP-AoI. Three sampling locations were selected within each AoI i) u/s impounded section, ii) dewatered section 10-15 km d/s of dam and iii) 10-15 km d/s of PH. In case of V-HEP the river is not accessible for long distance after the power house. Hence, the river could not be sampled for nearly 53 km after V-HEP power house. In S-HEP the river is accessible for sampling at one place before power house and two places after power house.

Methodology: The stations, S1 and S2 were sampled for the period of seven month only depending on the accessibility while the stations downstream to the V-HEP and S-HEP powerhouse (S3-S8) were sampled regularly at monthly intervals during September, 2017-August, 2018. Samples obtained from S7 were devoid of diatoms for which reason the results are not discussed for this station. The epilithic diatom samples were obtained by scraping a 3x3 cm^2 area of substrate from the river bed at a depth of 15 to 30 cm with the help of razor and brush at each station. Three samples were collected from three different flows (one from each) viz. turbulent flow, fast flow and slow flow. The samples were fixed in 4% formalin in field itself. In laboratory, the samples were first washed with distilled water and subjected to acid-peroxide treatment to remove organic coatings and to obtain clean frustules. The sample was taken in 100 ml beakers. Each sample was digested for 24 hours with an equal amount of concentrated hydrochloric acid (HCl). Following this treatment, the samples were washed multiple times with double distilled water to remove any remaining acid traces. The samples were then treated for 24 hours with hydrogen peroxide (H_2O_2) to digest the remaining debris before being washed with distilled water to remove any traces of it. The suspension was stirred before being placed on the coverslip drop by drop until it reached the edges and allowed to dry. The Naphrax (Brunel Microscopes Limited; Refractive index of 1.74) was then placed on a microscope slide and warmed on a hotplate at 40°C. The Naphrax mounts were examined under bright field using a BX-40 Trinocular Olympus Microscope (x10 and x15 wide field eyepiece) fitted with a PLANAPO x100 oil immersion objective under the bright field using different suitable filters to identify species.

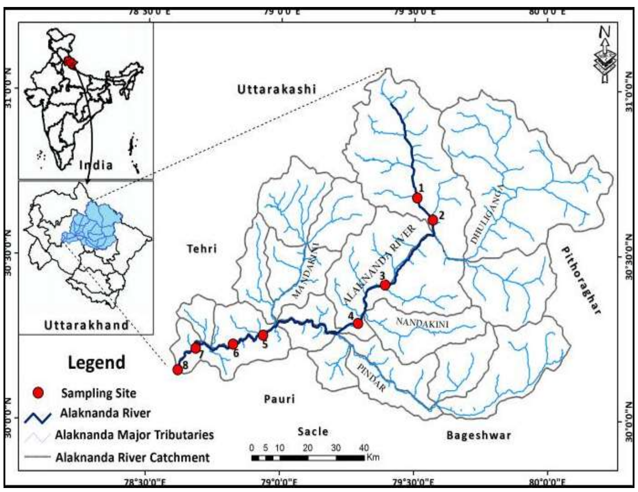

Fig. 1. Location of the sampling stations (red spots) on the river Alaknanda. The Vishnuprayag hydroelectric project (VHEP) near Lambagarh is located between S1 and S2 while Srinagar hydroelectric project (SHEP) between S5 and S6 near Srinagar

Species were identified according to standard literature (Hustedt 1985, Krammer and Lange-Bertalot 1986, Krammer 2002-2003). Diatom counts were performed on each flow till 100 to 150 valves were counted. Counts for all three flows were integrated to represent the maximum habitat. Relative abundance (as %) was computed to determine the dominant

Table 1. Geographical location of the sampling stations on the river Alaknanda and fall among stations

Station	Name	Lat (°N)	Long (°E)	Alt	Fall (m)	DBS (Km)
S1	1.2km u/s VHEP	30°40'37”	79°30'37”	2500		0
S2	Govind Ghat d/s VHEP	30°36'45”	79°33'55”	1800	700	9
S3	Birahi	30°24'37”	79°23'22”	1068	732	35
S4	Langasu	30°17'36”	79°17'18”	800	268	24
S5	Narkota	30°15'17”	78°55'46”	600	200	43
S6	Srinagar D/s SHEP	30°14'23”	78°49'57”	560	40	20
S7	Srinagar D/s SHEP-PH	30°13'42”	78°49'11”	535	25	5
S8	Bagwan	30°13'19”	78°40'54”	500	35	14

Acronyms: Lat- Latitude, Long- Longitude, Alt- Altitude (m asl), D/s - downstream, DBS- Distance between stations, VHEP- Vishnuprayag hydroelectric project, SHEP- Srinagar hydroelectric project, PH- powerhouse for each assemblage. Taxa with the highest relative abundance were considered dominant, and those with the second highest relative abundance were considered subdominant in the assemblage. The dominant and the sub-dominant characterized the assemblage.

RESULTS AND DISCUSSION

The diatom assemblages varied with seasons at S1 and S2. The assemblages exhibited more similarity within a season at S2 viz. *A. pyrenaicum* (Hustedt) Kobayasi-*A. minutissimum* Kutzing during summer and *A. pyrenaicum* - *Reimeria sinuata* during monsoon but differs in winter (*A. minutissimum* - *A. pyrenaicum* during November and *C. placentula* var. *euglypta* (Ehrenberg) Grunow-*A. minutissimum* during February) and less similarity within a season at S1. At S3, assemblages differed during winter and monsoon and occurred intermittently during summer. At S4, assemblages resembled during late winter (*A. pyrenaicum* - *Cymbella laevis* Naegeli in Kutzing during January and February) while differed during the rest period. During summer and winter, assemblages differed. In terms of dominants, *A. pyrenaicum* showed maximum occurrence round the year at S3 and S4. At S5, the assemblages show less variability among the seasons. At S6 and S8, assemblages varied at monthly intervals except few months of summer. *A. pyrenaicum* showed predominance at S5 and S8 like S3 and S4 whereas *A. minutissimum* exhibited predominance at S6 (Table 2). *A. pyrenaicum* - *A. minutissimum* (28%) followed by *A. minutissimum* - *A. pyrenaicum* (16%) showed the highest frequency among the diatom assemblages in the river (Table 3). Temporally, the number of assemblages were 4 at S1 and 5 each at S2, S3, S4, S5, S6 and S8. Spatially, the numbers of assemblage were relatively low with an exception in one or two months.

Developing hydropower projects in the Himalayas has various added advantages, including being a more sustainable kind of energy generation, being locally produced, and the river traits being appropriate for this type of operation. The increasing developmental activities and climate changes influences the ecological patterns of rivers in the Indian Himalayan region (Rawat et al 2020). The construction of hydroelectric projects is considered to be the most substantial anthropogenic impact on lotic ecosystems. Dams and barrages modify the natural hydrological regime of the river and consequently disrupt the continuum of a lotic ecosystem. These dams consequently effect the seasonality as well as day-to-day changes that are markedly different from natural flow patterns. As a result, ongoing human development jeopardises river habitats and ecosystems (Vorosmarty et al 2010). The hydropower developments on river Alaknanda, therefore, impacts the flow patterns due to the peaking requirements and hence, the ecosystem services.

During the present study, the diatom assemblages differed at monthly intervals at the majority of the stations, indicating lack of seasonality at these sites. In a year, 4-5 (approx.) assemblages were formed at each site, exhibiting the inconsistency of seasonal trends. In the previous studies, the highest frequency of *Achnanthidium minutissimum*-*Achnanthidium nodosa* from winter to summer (October to May) was recorded on the Alaknanda River at Srinagar (Nautiyal 2005). This shows high seasonality in the assemblages of unregulated rivers. In contrast, the assemblages displayed relatively more temporal than spatial

Table 2. Epilithic diatom assemblages during different seasons in the river Alaknanda during 2017-18

Season	Month	S1	S2	S3	S4	S5	S6	S8
Winter	November	Rs-Am	Am-Ap	Am-Ap	Ap-Am	Ap - Am	Am - Ami	Si - Am
	December	SF*	SF*	Ap-Am	Cl-Ap	Ap - Am	Am - Ap	Ap - Am
	January	SF*	SF*	Ap-Cl	Ap-Cl	Ap - Cpe	Am - Ami	Cep - Ap
	February	Ap-Am	Cpe-Am	Ap-Cpe	Ap-Cl	Ap - Si	Cep - Am	Ap - Cep
Summer	March	Am-Ap	Ap-Dm	Ap-Cpe	Ap-Cl	Ap - Cl	Cep - Ap	Ap - Cep
	April	NS	NS	NS	NS	NS	Am - Cep	NS
	May	Ap-Cep	Ap-Am	Ap-Am	Am-Ap	Ap - Cpe	Am - Ap	Ap - Am
	June	Ap-Am	Ap-Am	Ap-Am	Ap-Am	Ap - Cpe	Am - Ap	Ap - Am
Monsoon	July	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	August	Nil	Nil	Nil	Nil	Nil	Nil	Nil
	September	Nil	Ap-Rs	Ap-Rs	Ap-Am	Nil	Nil	Nil
	October	Ap-Am	Ap-Rs	Am-Ap	Ap-Nd	Cp - Am	Am - Ap	Np - Am

Acronyms: SF*- Snow fed, NS- Not sampled, Am- *Achnanthidium minutissimum, Ap- A. pyrenaicum, Ami- A. microcephala, Cpe- Cocconeis placentula var euglypta, Cp- C. placentula, Cl- Cymbella laevis, Cep- Cymbella excisa var procera, Rs- Reimeria sinuata, Si- Synedra inaequalis, Dm- Diatoma moniliformis, Nd- Nitzchia dissipata, Np- N. palea*

Table 3. Colour chart indicating the diatom assemblages having high frequency during different seasons

Season	Months	S1	S2	S3	S4	S5	S6	S7	S8	Assemblage (Frequency in %)
Winter	November		Am - Ap	Am - Ap	Ap - Am	Ap - Am				Ap - Cpe (9)
	December			Ap - Am	Ap - Am	Ap - Am	Am - Ap		Ap - Am	Ap - Cl (9)
	January			Ap - Cl	Ap - Cl	Ap - Cpe				Ap - Cep (5)
	February	Ap - Am		Ap - Cpe	Ap - Cl				Ap - Cep	Ap - Am (28)
Summer	March	Am - Ap		Ap - Cpe	Ap - Cl	Ap - Cl			Ap - Cep	Am - Ap (16)
	April									
	May	Ap - Cep	Ap - Am	Ap - Am	Am - Ap	Ap - Cpe	Am - Ap		Ap - Am	
	June	Ap - Am	Ap - Am	Ap - Am		Ap - Cpe	Am - Ap		Ap - Am	
Monsoon	July									
	August									
	September				Ap - Am					
	October	Ap - Am		Am - Ap			Am - Ap			

heterogeneity during the present study. Kokai et al (2019) also found pronounced temporal heterogeneity in phytobenthos composition than spatial heterogeneity. It is evident from the present study that the altered hydrology perturbs seasonality of the assemblages.

The composition, structure and seasonal trends of phytoplankton alters due to the changes in water level and the general environmental drivers driving the change are flushing, dilution and intervention with the seasonal water stratification processes (Li et al 2018). Goldenberg Vilar et al (2022) observed sensitivity of diatom communities to the effect of flow alteration even during one single season. Krajenbrink et al (2019) highlighted the effects of flow regulation on diatom communities and found that autumn diatom samples showed higher sensitivity to the effects of river regulation, with more indicator taxa found than in spring samples. The diatom assemblages demonstrate unstable river ecosystem. The maximum occurrence of *A. pyrenaicum* or *A. minutissimum* as a dominant indicates that the hydroelectric project has altered the benthic diatom assemblages, as more tolerant taxa or indifferent taxa have replaced the sensitive dominants. Goldenberg Vilar et al (2022) also reported higher abundance of *A. minutissimum* in altered sites. Furthermore, because diatoms are at the base of the ecosystem's trophic structure, they are more sensitive to changes in water chemistry, particularly nutrients, the availability of which is inhibited by the reduced quantum and hindrance to river flow. The assemblage lack predictable pattern attributed to modified hydrological regime for peaking purpose resulting in extremely varying flow regimes (on a daily basis) throughout the year. Unlike a natural ecosystem where the peak occurs invariably in same month all along the river, the occurrence of peak in different months of a season indicates impact of hydropower on assemblages.

CONCLUSIONS

The assemblages at S1 and S2 varied during different seasons. Few samples at S1 and S2 preclude any conclusions about the seasonality of the assemblages. At S3, S4, S5, S6 and S8, the assemblages differed from month to month showing lack of seasonality at these stations. Assemblages tend to predominate in a natural hydrological regime which changes seasonally. If regime is manipulated, the assemblages become vulnerable to modifications or replacement resulting in a lack of seasonality as various physical and chemical gradients are lost. These were interpreted as perturbations caused by discharges held and released for the purpose of generating electricity, implying the unstable nature of these communities in the river ecosystem impacted by serial impoundments.

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Morphometric and Meristic Analysis of Mirror Carp (*Cyprinus carpio* var. *specularis)* Collected from Dal Lake, Kashmir

S. Majeed, F.A. Bhat* and I. Mohd

Faculty of Fisheries, Rangil, Ganderbal, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir-190 006, India
**E-mail: fabhat_fb@yahoo.com*

Abstract: One hundred twenty-nine (129) fish samples of mirror carp, *Cyprinus carpio* var. *specularis of* variable sizes were collected for demonstrating the morphometric and meristic characteristics of this specie in the Dal Lake, Kashmir during January-August 2022. Morphometric characters (seventeen) and meristic counts (six characters) for each specimen were examined. The morphometric characters showed gradual increase as the body length and weight increases. The meristic count of anal fin rays was constant in all groups, while other parameters of meristic count varied.

Keywords: Mirror carp, Morphometric, Meristic, Dal Lake

The mirror carp, *Cyprinus carpio* var. *specularis*, is an exotic fish and a member of the Cyprinidae family, one of the largest families of freshwater fish. Europe is the home of the mirror carp. In 1955-1966, mirror carp of the German genotype were introduced into Dal Lake from Himachal Pradesh (Jhingran and Sehgal 1978). Dal Lake, a Himalayan urban lake, is situated in Srinagar, Jammu and Kashmir (J&K), at an elevation of 1,775 m with a mean latitude and longitude of 74°52'E and 34°07'N, respectively. Dal lake has been home to 17 species of fish (Das and Subla 1963, Jayaram 1974), 106 species of macrophytes from 30 families (Kaul and Zutshi 1967), 72 species of zooplankton (Yousuf and Parveen 1989), and 139 taxa of phytoplankters (Kundangar 1994). Main aim of the present study was to provide detailed, baseline information about the morphometric characters and meristic counts of this fish species.

MATERIAL AND METHODS

Collection of Specimens: A total of One hundred twenty-nine (129) specimens were collected from Dal Lake (34°07'N 74° 52'E) during January-August 2022. The collected samples were transported to Fishery Resource Management Laboratory at Faculty of Fisheries, Rangil for biological analysis.

Morphometry: All morphometric characters were measured to the nearest millimetres (mm) with digital calliper following the method described by Lowe-McConnel (1971) and Dwivedi and Menezes (1974). Weight of samples was recorded to nearest grams (g). The seventeen morphometric parameters were measured (Fig. 1). Based on their range, several morphometric characters were then divided into genetically (Narrow range, 10%), intermediately (Moderate range, 10-15%), and environmentally (Vast range, >15%) controlled characters (Johal et al 1994). The total length was considered as an independent variable while as other characters were considered as dependent variables. The equation Y = a + bX, was used to identify relationships where Y and X are the dependent and independent variables, respectively, a is the constant (intercept), and b is the regression coefficient.

Meristic: Meristic approaches entail counting the structures of fishes such as lateral line scales, fin spines and rays, gill rackers and branchiostegal rays to determine the species and class of fish. Counts were made on the left side of the body of samples. Fin formula represents the meristic count of a fish. The six meristic characters were counted: dorsal fin ray and spines, anal fin rays and spines, pectoral fin ray and spines, pelvic fin rays and spines, caudal fin rays and spines and lateral line scale count.

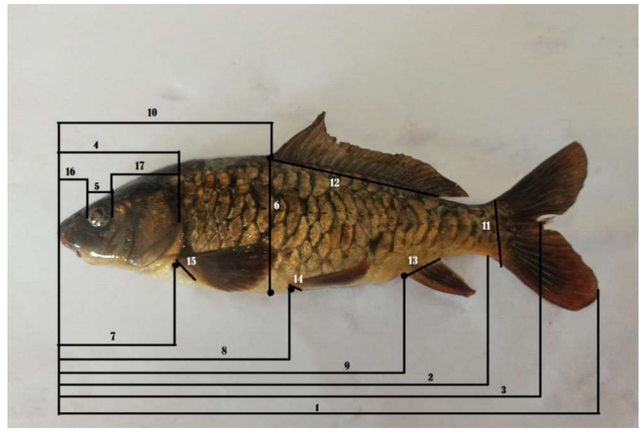
Statistical analyses: All statistical analyses were performed using MS-Excel 2007 and IBM SPSS Statistics 21.0 package.

RESULTS AND DISCUSSION

Morphometry: The various morphometric characters of *C. carpio* var. *specularis* and their relationship are shown in Table 1-3 and Figure 1- 2. The mean total length and the standard length was 185.63 and 151.39 cm respectively. The total weight ranged from 37.83 to 602.01 g. Correlation coefficient (r) was highest between total length and standard length (0.989) followed by total length and forked length (0.985) indicating high degree of correlation between the characters compared while the least degree of correlation was between total length and eye diameter (0.737). However with respect to head length (HL), highest correlation coefficient was of post-orbital length (0.957). Linear relationships were observed between all the independent and dependent characters (Fig. 1). Bhat et al (2010) while studying the morphometric characteristics of *Schizothorax*

Table 1. Various morphometric characters of *C. carpio* var. *specularis*

Statistical estimates	Min (mm)	Max (mm)	Mean (mm)
Total length	137.51	318.06	185.63
Standard length	112.19	290.48	151.39
Forked length	113.6	264.47	164.73
Head length	34.25	70.53	45.336
Eye diameter	5.71	11.66	8.53
Body depth	39.65	102.73	51.35
Pre-pectoral length	34.55	70.01	45.69
Pre-pelvic length	60.05	123.23	76.97
Pre-anal length	74.71	192.24	112.76
Pre-dorsal length	45.7	136.12	75.95
Caudal peduncle depth	13.23	43.48	20.28
Dorsal-fin base length	38.06	98.37	53.57
Anal-fin base length	9.61	27.72	13.25
Pelvic-fin base length	4.17	11.48	6.77
Pectoral-fin base length	4.14	13.37	7.84
Pre-orbital length	11.14	29.3	16.10
Post-orbital length	15.41	32.73	21.05
Weight	37.83	602.01	106.39



1. Total length (TL)
2. Standard length (SL)
3. Forked length (FL)
4. Head length (HL)
5. Eye diameter (ED)
6. Body depth (BD)
7. Pre-pectoral length (PPL)
8. Pre-pelvic length (PVL)
9. Pre-anal length (PAL)
10. Pre-dorsal length (PDL)
11. Caudal peduncle depth
12. Dorsal-fin base length (DFBL)
13. Anal-fin base length (AFBL)
14. Pelvic-fin base length (PFBL)
15. Pectoral-fin base length (PFBL)
16. Pre-orbital length (PrOL)
17. Post-orbital length (PoOL)

Fig. 1. Schematic illustration of measurements taken on the body of (*Cyprinus carpio* var.*specularis)* from the Dal Lake

Table 2. Relationship between total length and various morphometric characters of *C. carpio* var. *specularis*

Statistical estimates	Standard deviation	Correlation coefficient (r)	Regression equation
Standard length (SL)	35.27583	0.989	y = 0.948x - 24.71
Forked length (FL)	31.435619	0.985	y = 0.842x + 8.380
Body depth (BD)	12.58996	0.923	y = 0.316x - 7.311
Head length (HL)	8.04453	0.96	y = 0.21x + 6.344
Eye diameter (ED)	1.35957	0.737	y = 0.0272x + 3.4812
Pre-Pectoral length (PPCL)	8.36400	0.877	y = 0.199x + 8.68
Pre-Pelvic length (PPVL)	14.44091	0.907	y = 0.356x + 10.8
Pre-anal length (PAL)	23.63612	0.921	y = 0.591x + 2.895
Pre-dorsal length (PDL)	17.39363	0.855	y = 0.406x + 0.432
Caudal peduncle depth (CPD)	5.76005	0.949	y = 0.148x - 7.300
Dorsal-fin base length (DFBL)	11.33109	0.964	y = 0.297x - 1.565
Anal-fin base length (AFBL)	3.44915	0.928	y = 0.087x - 2.914
Pelvic-fin base length (PVFBL)	1.90767	0.745	y = 0.038x - 0.404
Pectoral-fin base length (PFBL)	1.77705	0.879	y = 0.042x - 0.043
Pre-orbital length	3.94399	0.89	y = 0.0955x - 1.6209
Post-orbital length	4.36857	0.923	y = 0.1096x + 0.7115

Table 3. Relationship between head length and various morphometric characters of *C. carpio* var. *specularis*

Statistical estimates	Standard deviation	Correlation coefficient (r)	Regression equation
Eye diameter (ED)	1.35957	0.789	y = 0.1334x + 2.4895
Pre-orbital length (PrO)	3.94399	0.909	y = 0.4456x - 4.0968
Post-orbital length (PoO)	4.36857	0.957	y = 0.5194x - 2.4942

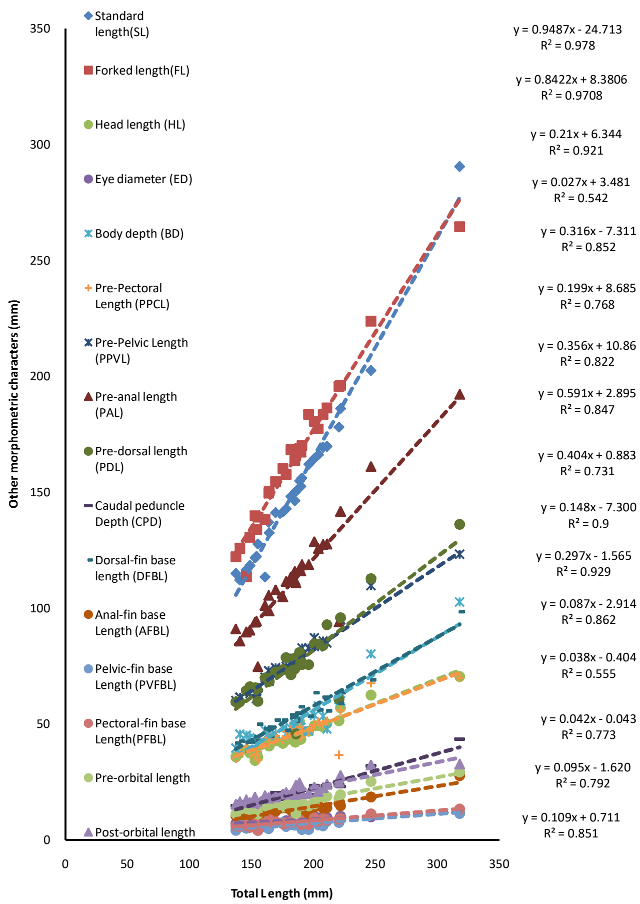


Fig. 1. Relationship between total length and other morphometric characters in *C. carpio* var. *specularis*

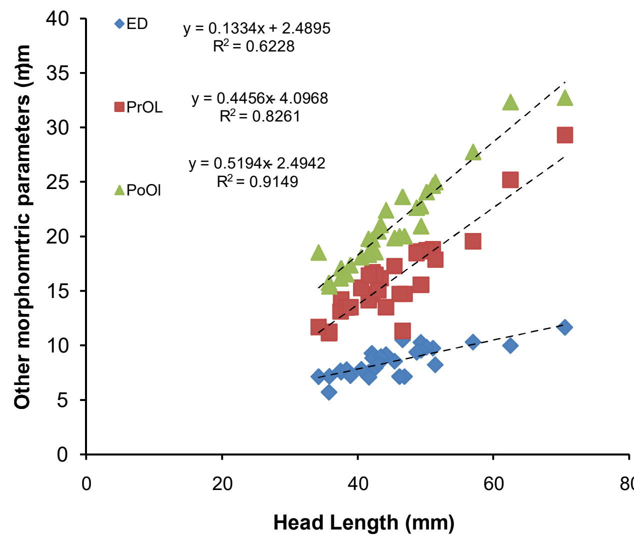


Fig. 2. Relationship between head length, pre-orbital length, post-orbital length v/s head length

sp. in the River Lidder of Kashmir reported least growth in body depth (0.1730) and maximum growth in standard length (0.9080) with respect to the total length of the fish. Shah et al (2011) investigated the morphometry of farmed rainbow trout in Kashmir and reported very high degree of relationship among the characters compared, with the highest degree of correlation (0.99) between total length and fork length and lowest value (0.82) between total length and body depth.

The morphometric characters have been categorized on the basis of range difference as mentioned above. The 13 characters such as SL, FL, HL, BD, PPVL, PPCL, PDL, PAL, CPD, DFBL, AFBL, PrO and PoO in percentage of total length were environmentally controlled while characters such as ED, PVFBL, and PFBL were genetically controlled characters. However, with respect to head length, ED is included in genetically controlled while PrO and PoO in environmentally controlled characters. Negi and Negi (2010) analysed the morphometric characters of *Schizothorax richardsonii* and reported that out of 21 characters studied, 19 were genetically controlled, 1 intermediate and 1 character environmentally controlled.

Meristic: Six meristic characteristics, including the number of lateral line scales, dorsal fin rays, pectoral fin rays, pelvic or ventral fin rays, caudal fin rays, and anal fin rays, have been counted and have a definite number, but they can vary and fall within a range (Table 3). The lateral line count ranged from 19-35, dorsal fin 19-23, pectoral fin 11-16, pelvic fin 6-9 and caudal fin 19-22. Anal fin rays count (6) was constant in all samples. These findings show that meristic counts of *Cyprinus carpio* var. *specularis showed variation while anal fin count showed similarities.* Meristic characters are genetically controlled but their expression may be modified by the environment. Singh *et al* (2018) reported caudal fin rays and anal fin rays ranging between 19-21 and 8-9 whereas dorsal fin rays, pectoral fin rays and ventral fin rays to be 7, 9 and 5, respectively in *Aorichthys seenghala*. Fin formula calculated for *Cyprinus carpio* var. *specularis* for the present study was: D: 1/19-23, P: 11-16, V: 6-9, A: 6, C: 19-22, L1: 19-35. Talwar and Jhingran (2001) reported the fin formula of *Cyprinus carpio* var. *communis* as D. 3-4/18-20, P1: 1/15, P2: 1/8, A. 3-5, L1: 30-40. This study focus on morphometric and meristic count of mirror carp as there was no previous work done on this aspect from Dal Lake.

CONCLUSION

Various morphometric characters studied showed a high degree of correlation(r) with each other. The coefficient of correlation (r^2) was maximum between total length and standard length and least between total length and pelvic- fin base length Further, meristic counts continuously change when the fish's body weight and length increase or decrease. The information generated serves as a foundation for the growth and effective management of Kashmir Valley's carp fishery as well as for a deeper comprehension of its biology and growth.

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Study of Biometric Attributes of Plug Type Tomato Seedlings Pertinent to Transplanter Design

Ankit Sharma, Sanjay Khar[1], Divakar Chaudhary[1] and Prerna Thakur[2]

Farm Machinery & Power Engineering, Punjab Agricultural University, Ludhiana-141 004, India
[1]Division of Agricultural Engineering, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (SKUAST-Jammu), Jammu-180 009, India
[2]Krishi Vigyan Kendra, Moga-142 001, India
E-mail: ankitsharma@pau.edu

Abstract: The biometric attributes such as seedling length, weight, plug compactness, stem and spread diameter of 25-, 32-, and 40-days old tomato plug seedlings relevant to the design and selection of various components of vegetable transplanter were investigated. The seedlings were grown in pro-trays having truncated square pyramid (104 cells) and right circular cone (98 cells) shape cells. The seedling length and plug compactness were more in truncated square pyramid cells pro-tray whereas seedlings' weight, stem diameter, and spread diameter were more in truncated right circular cone cells pro-tray. The maximum seedling length and plug compactness score were 208 mm and 8.8 corresponding to truncated square pyramid cells and 40 days seedling age on the other hand maximum seedlings weight, stem diameter, and spread diameter was 10.57 g, 3.02, and 136 mm corresponding to truncated right circular cone and 40 days seedling age. With the increase in seedling age all of the selected attributes of tomato seedlings increased for both types of cells.

Keywords: Attributes, Biometric, Cell, Pro-tray, Tomato

In India, more than 70 different types of vegetables are grown, but only a few are grown in portrays. Sowing, planting, and transplanting methods are used to propagate vegetable crops such as tomato, chilli, onion, cauliflower, brinjal, and cabbage. These crops are grown in a nursery (Khadatkar et al 2020). Among this tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops grown for their fleshy fruits and is a significant commercial and dietary vegetable crop. Tomato area, production, and productivity in India were approximately 814 thousand hectares, 20515 thousand MT, and 25.20 MT·ha^{-1}, respectively, in 2018-19 (Gaikwad et al 2020). The growing importance of agricultural operations utilising modern machinery for horticultural crop production necessitates a better understanding of their engineering properties so that machines, processes, and handling operations can be designed for maximum efficiency and end-product quality (Khadatkar et al 2020). Physical properties such as shape, size, height, weight, stem diameter, etc are important parameters to consider when designing a transplanter for vegetable seedlings (Gaikwad 2010, Turbathmath 2010, Pandirwar et al 2015). It is critical to have an accurate estimate of the shape, size, weight, height, and other physical and mechanical properties that may be used as engineering parameters for product development. Furthermore, mechanical damage to seedlings during handling and transplanting can have a serious impact on viability, germination, damage, growth, and crop yield (Gaikwad 2010, Pandirwar et al 2015, Khadatkar 2019).

Some researchers investigated the engineering and biometric properties of the onion crop concerning crop-based machine design (Khura et al 2010, Turbathmath 2010, Pandirwar et al 2015). Some research has also been conducted on the engineering properties of garlic to design crop production and processing equipment such as planting, handling, storing, aeration, drying, bulb breaking, and peeling (Masoumi et al 2006, Manjunatha et al 2008, Rathinakumari et al 2015, Bakhtiari and Ahmed 2015). Abubakar et al (2020) determined the physical and mechanical properties of four-week-old tomato seedlings such as stem thickness, height, weight, spread diameter, angle of friction, frictional coefficient, impact, compressive and tensile properties for the design of a mechanical tomato transplanter. Khadatkar et al (2020) investigated biometric properties such as weight, stem diameter, height, critical canopy diameter, drop shatter height, compressive strength, and coefficient of static friction that were relevant to the design of a vegetable transplanter for 30, 45, and 60-day old tomato and chilli plug seedlings. Xifeng et al (2015) investigated the physical and mechanical features of a 23-day tomato seedling pot that were directly related to the design of autonomous transplanting machine key components such as the seedling picking and transplanting mechanism. Therefore, keeping in view the importance of biometric attributes relevant to the development of transplanting machinery, the present study was conducted to determine the biometric attributes of tomato vegetable seedlings, which could be useful in designing and development tomato transplanters.

MATERIAL AND METHODS

Nursery raising in pro-trays: Standard agronomic practises were used to grow the seedlings. The soilless growing medium, which is made by combining coco peat, vermiculite, and perlite in a 3:1:1 ratio, was placed in the two different type of pro-trays having the square and round cells. Per cell, one seed was sown. For seed sowing, small depressions were made in the centre of the plugs with fingertips or mechanical tools. Depending on the season or the optimum temperature required for early and better germination, the tomato trays were then placed in a polyhouse or shade. Every day, water was sprayed evenly across each tray using a fine sprinkler boom.

Seedling age: The seedling age of 32 days is recommended for tomato crop seedling transplanting. In addition to the recommended seedling transplanting age, two additional seedling ages (one week before and after the recommended seedling age) were chosen to investigate the effect of seedling age variation. The tomato variety Himsona seedlings at ages 25, 32, and 40 days were chosen for the current study to assess the impact of different seedling ages on the developed transplanter.

Cells type: Two trays with cell numbers 104 and 98 and morphologies of truncated square pyramid (C_s) and truncated right circular cone (C_r) were chosen from the local market, with measurements displayed in Figure 1. The volume of truncated square pyramid cell was 16.99 cm^3 whereas truncated right circular cone cell had volume of 20.49 cm^3. Figure 2 depicts a dimensional image of a truncated square and right circular cone shape cell.

Measurement of Biometric Properties

Seedling weight (S_w): Thirty seedlings were randomly selected and weighted using an electronic weighing balance with a minimum count of 1 g.

Seedling length (S_l): To determine the average length, the seedlings were gently pulled from the plug and 30 observations were made in each case. The seedling length of each sample was measured using the ASNS (2014) method, in which the seedlings were laid on a table, and the distance from the tip of the seedling to the end of its root was measured using a 300 mm scale with an accuracy of 1 mm.

Seedling stem diameter (S_s): The stem diameter of thirty uprooted seedlings of various ages and cells was measured using a digital micrometre with a minimum count of 0.01 mm. To maintain uniformity, the plant's stem diameter was measured at a height of 20 mm from the bottom end (Mohsenin 1986).

Seedling spread diameter (S_d): The 30 randomly selected tomato seedlings samples were placed in the field in their natural state, and the spread diameter was measured using a ruler with a 1 mm accuracy (ASNS 2014).

Seedling plug compactness (S_c): Based on the qualitative evaluation, a plucking rating of 10 was assigned based on the damage to the plug. It received a 10 if the nursery seedlings were removed without damaging the plug. At random, plugs were taken from thirty plants of varying ages and cell types.

Statistical analysis: Descriptive statistical analysis was performed using SPSS (version 26) to investigate the effect of different seedling ages and cell type/shape on the biometric properties of tomato seedlings.

RESULTS AND DISCUSSION

Seedling length (S_l): At 25 days and 40 days of seedling

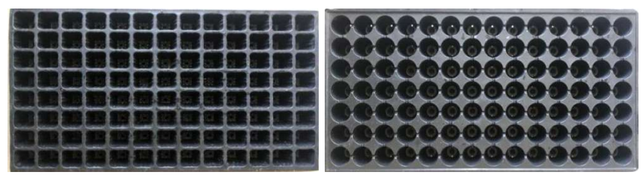

Fig. 1. Truncated square pyramid (C_s) and right circular cone (C_r) cell shape pro-trays

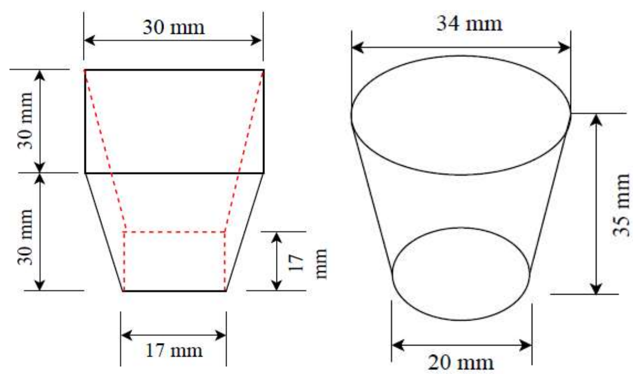

Fig. 2. Square and round cell

Fig. 3. Measurement of the seedling stem diameter and length

age, the average minimum and maximum seedling lengths were 118.67 mm and 208 mm, respectively. At 25 days seedling age, cell C_s and C_r had average minimum seedling lengths of 118.67 mm and 144.33 mm, respectively. At 40 days of age, the cell C_s and C_r had the longest average seedling lengths of 208 mm and 195.5 mm, respectively (Table 1). The effect of seedling age on seedling length was significant whereas the effect of cell type on seedling length was not. The interaction between seedling age and cell effect was also significant.

Seedling weight (S_w): The average minimum and maximum seedling weight of 8.73 g and 10.79 g was at 25 days and 40 days seedling age respectively. The average minimum seedling weight of 8.73 g and 9.25 g was observed in the case of cell C_s and C_r at 25 days seedling age. The average maximum seedling weight of 9.87 g and 10.79 g was in cell C_s and C_r at 40 days seedling age respectively (Table 1). The effect of seedling age on seedling weight was non-significant while the effect of cell type was significant. The seedlings age and the cell type interaction was insignificant.

Seedling stem diameter (S_s): The average minimum stem diameter of 1.82 mm and 2.40 mm was observed in cell C_s and C_r at 25 days seedling age. The average maximum stem diameter of 2.95 mm and 3.02 mm was in cell C_s and C_r at 40 days seedling age respectively (Table 1). The effect of seedling age and cell type on stem diameter was significant. The seedling age and cell type interaction was also significant.

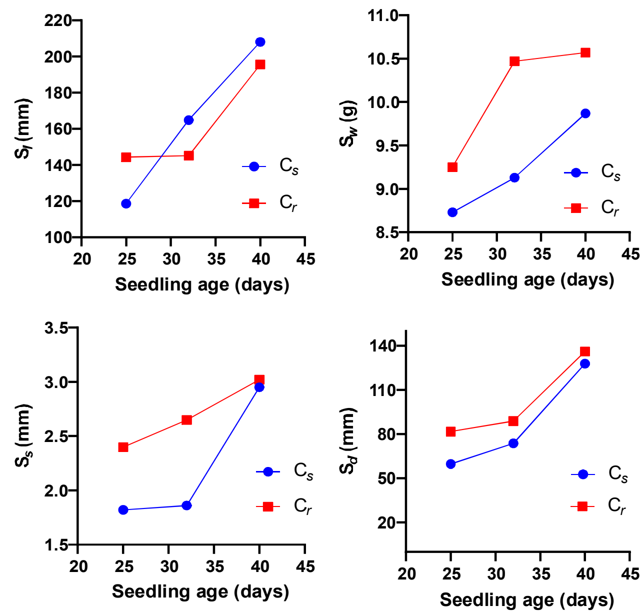

Fig. 4. Effect of the seedling age and cell type on the S_l, S_w, S_s and S_d

Table 1. Biometric attributes of tomato seedling at different age and cell type

Attributes	S_l (mm)		S_w (g)		S_s (mm)		S_d (mm)	
	Seedling age							
	25 days							
Cell shape	C_s	C_r	C_s	C_r	C_s	C_r	C_s	C_r
Maximum	140	172	11.6	11.60	2.00	2.57	72	120
Minimum	95	125	6.50	8.10	1.50	2.25	45	55
Average	118.67	144.33	8.73	9.25	1.82	2.40	59.67	81.67
SD	16.15	17.44	1.83	1.24	0.176	0.13	10.13	22.54
CV (%)	13.61	12.09	20.96	13.45	9.674	5.39	16.98	27.61
	32 days							
Maximum	185	165	10.0	11.80	2.30	3.27	90	102
Minimum	130	116	8.0	8.50	1.60	2.40	40	78
Average	164.83	171.17	9.13	10.47	1.86	2.65	73.67	88.83
SD	19.26	18.93	0.70	1.23	0.24	0.35	18.67	10.09
CV (%)	11.68	13.04	7.64	11.71	13.06	13.27	25.35	11.36
	40 days							
Maximum	245	236	11.0	12.20	3.15	3.50	154	175
Minimum	182	148	8.70	7.50	2.77	2.78	100	109
Average	208.00	195.50	9.87	10.79	2.95	3.02	127.83	136.00
SD	25.67	34.75	0.87	1.94	0.14	0.25	17.74	25.78
CV (%)	12.34	17.78	8.85	18.35	4.85	8.37	13.87	18.96

Table 2. Plug compactness score of tomato seedling at selected age and cell type

Seedling age	25 days		32 days		40 days	
Cell type	C_s	C_r	C_s	C_r	C_s	C_r
Maximum	9	9	10	10	9	10
Minimum	4	4	6	5	5	5
Average	6.7	6.4	7.9	7.3	8.8	8.4
SD	1.64	1.51	1.66	1.64	1.40	1.71
CV (%)	24.42	23.52	21.05	22.42	15.89	20.39

Seedling spread diameter (S_d): The average minimum and maximum seedling spread diameter of 59.67 mm and 136.00 mm was at 25 days and 40 days seedling age respectively. The average minimum seedling spread diameter of 59.67 mm and 81.67 mm was in cell C_s and C_r was observed at 25 days seedling age. The average maximum seedling spread diameter of 127.83 mm and 136.00 mm was in cell C_s and C_r at 40 days seedling age respectively (Table 1). The effect of seedling age and cell type on seedling spread diameter was significant whereas their interaction was found to be insignificant.

Plug compactness (S_c): The average minimum and maximum plug compactness score of 6.4 and 8.8 was at 25 days and 40 days seedling age respectively. The average minimum plug compactness score of 6.7 and 6.4 was in cell C_s and C_r at 25 days seedling age whereas the average maximum plug compactness score of 8.8 and 8.4 was in cell C_s and C_r respectively (Table 2). The influence of cell type on plug compactness score was not statistically significant. Effect of seedling age was significant and interaction between cell type and seedling age was insignificant.

The tomato seedling attributes such as seedling length (mm), weight (g), stem diameter (mm), spread diameter (mm) and plug compactness selected for the present study differs significantly under different seedling ages and increased with an increase in the seedling age for each type of cell shape. This could be due to the maturation of tomato seedlings with age. The variation in physical attributes caused by changes in cell shapes was attributable to the seedlings' differing responses to varying amounts of cell medium as seedling age increased. Bhambota et al (2019) observed that seedling age, medium, and cell size had a significant influence on plant height, stem diameter, and spread diameter (seedling growth parameters) in tomato, brinjal, and chilli crops. They also stated that seedling growth characteristics increased with seedling age.

CONCLUSIONS

For both kinds of cells, all of the specified attributes of tomato seedlings were observed to increase with seedling age. The seedling length and plug compactness score of truncated square pyramid cells were larger, but the seedling weight, stem diameter, and spread diameter of truncated right circular cone cells were greater. The maximum seedling length and plug compactness score were 208 mm and 8.8, respectively, corresponding to truncated square pyramid cells and 40 days seedling age. The maximum seedling weight, stem diameter, and spread diameter, respectively, were 10.57 g, 3.02 mm, and 136 days seedling age. These characteristics of vegetable seedlings are significant for designing and selecting various components of a vegetable transplanter.

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Estimating Volume and Mass of Tomato Fruits by Image Processing Technique

Sandhya, M. Kumar and D. Singh[1]

Department of Processing & Food Engineering, [1]Department of Electrical Engineering & Information Technology
Punjab Agricultural University, Ludhiana-141 004, India
E-mail: sandhya-pfe@pau.edu

Abstract: A technique based on image processing was developed to determine volume and mass of tomato fruits. The images of different grades of tomato were attained using a digital camera. A MATLAB based algorithm was developed to enumerate and process these digital images. The geometric characteristics such as axial dimensions, mass, volume, density, sphericity, aspect ratio and ellipsoid ratio were recorded. The size of tomato varied from 30.00-77.62 mm. The bulk density was maximum (0.26 g/cc) for tomato of size 57-66 mm. The aspect ratio was higher than unity for tomatoes of all grades indicating the variation in length with respect to width. The differences between two methods were normally distributed and predictable to lie between M - 1.96SD and M + 1.96SD, known as 95% limits of agreement. The paired samples t-test results showed that parameters observed with image processing method was not significantly different from the those measured using vernier caliper. A linear relationship between mass of tomato and the projected area, volume and axial dimensions was also developed for calculation of mass using image processing. This information can be used to design and develop sizing systems.

Keywords: Tomato, Image processing, Volume, Mass, Grading

The knowledge of engineering properties of horticultural products is very important in developing new consumer products, evaluating and retaining the quality of products and designing of machines, processes and controls. The physical properties of food materials (raw, unprocessed and processed) include particle size and shape, density, surface area and porosity. Among all the important quality parameters, fruit size and shape are one which is mostly preferred by consumers i.e. consumer prefers fruits of uniform size and equal weight. So, the determination of fruit size and shape is very important in meeting the standards of quality parameters which results in monitoring the increasing market growth. The determination of physical properties such as size, unit mass, volume, sphericity and density using advanced technologies were reported by many researchers. In recent researches, it has been estimated that there is a huge loss of crop before consumption because of poor handling, storage, transportation and marketing practices. One of the major reasons for this loss is the time-consuming manual grading. Grading of the agricultural produce is considered very important as it improves handling, packaging, transportation and other post-harvest operations. The process of grading of fruit starts with the sorting of fruits by size, shape and colour by humans assessed by sight and feel. The increasing cost of labour and also demand for consistency in quality of products lead to mechanization of the sorting process (Tabatabaeefar and Rajabipour 2005, Lorestani and Tabatabaeefar 2006, Shahi-Gharahlaretal 2009, Adebowale et al 2011, Seyedabadiet al 2011, Ercisli et al 2012, Shahbazi and Rahmati 2013).

The application of image processing-based methods in agricultural activities has been developed for years (Lak 2011). Nowadays, commercial fruits such as strawberries, orange, peaches, tomato and apples have been graded by the use of image processing and machine-vision technology (Spreer 2009). The main components of machine-vision technology consist of a color CCD camera with an image capturing device and a lighting source to evaluate fruit based on different engineering properties such as size, shape, color and defection. Due to the availability of infrastructures, the automated sorting/ grading in various food industries had suffered substantial growth in the developed and developing countries. The application of computer in field of agriculture and food industries has resulted in better sorting, grading of fresh crops, recognition of defects such as cracks, dark spots and bruises on fresh fruits and seeds. So, automation is one of the most important aspects of agricultural mechanization. It allows improvement in efficiency, increase in capacity and protection to human workers from tedious and hazardous activities. The digital image processing has become very important and more probable to many areas including agricultural industry (Yimyam et al 2005, Chalidabhongse 2006, Bulanon 2012). The use of machine vision knowledge for quality examination, classification, sorting, and grading agricultural products is becoming more fascinating (Teoh 2010). This technology has been extensively used in the agricultural and food industry for evaluation and inspection as they offer suitable, quick and economic assessment. The automated examination of produce using this technology not only results in labor savings, but also advances inspection objectivity (Valente 2009, Spreer 2009). The development in hardware and software for digital image processing and their use in analysis of food crops have inspired several studies for the development of the system which can assess the quality of different foods. So as the manual and mechanical system which is currently being used for sorting/grading is labour intensive and also the new technology of image processing has not been fully explored in India for up gradation of the sorting/grading equipment, there is a need to develop such system which can meet the demand of the products in market without compromising the quality parameters. The present study has been planned to develop a system based on image processing technology to perform functions of sorting/grading based on volume and mass with greater precision at a faster rate without any drudgery.

MATERIAL AND METHODS

The tomato of variety *Punjab Chhuhara* was considered for the present study. A total of 25 fruits each of different grades of tomato were selected at random from the storage piles. The mass of each fruit was measured by an electronic weighing scale with an accuracy of ±0.1g. The axial dimensions (length, width and thickness) of tomato were measured using a digital vernier caliper with an accuracy of 0.01mm. The other parameters like shape, density, sphericity and true volume were determined using standard methods (Mohsenin 1986). Based on the shapes of tomato i.e. considering them to be ellipsoid, volume of fruits was calculated using three axial dimensions of fruits and geometric mean diameter. The following equations were used in calculations.

$$\text{Volume of ellipsoid} = \frac{4\pi}{3} \times L \times W \times T(\text{mm}^3)$$

Where L, W T are length, width, thickness in mm

$$\text{Change in volume (\%)} = \frac{\text{True volume - Calculated volume}}{\text{True volume}} \times 100$$

The same parameters were determined using image processing technique also. The setup of image processing consisted of a digital camera (AF-S DX NIKKOR 18-55mm f/3.5-5.6G VR II) connected to computer having image processing software. The camera was mounted on the image acquisition box for keeping the standardized distance. The height of optical lens of camera was tested for three different heights based on the size of tomato of different grades and height with the best results was selected. For tomato, the different heights of optical lenses tested were 145mm, 160mm and 175mm. Among them, height of 160mm was selected for capturing images of tomato. Images were captured in natural illumination. The camera was mounted on the tripod stand for keeping the distance of the fruit from the camera uniform. The analysis of the images of tomato for different grades was done using Image processing software (MATLAB R2013a, version 8.1). The flowchart showing image analysis algorithm used for processing of different images of tomato is given in Figure 1. The fruit images were calibrated for axial dimensions and other geometric properties by using images of a square sheet of black colour of size 5cm x 5cm under similar conditions. The data related to geometrical features attained by image processing of tomato was compared with the measured physical parameters and a correlation was studied between measured parameter (size, volume etc.) and those analyzed from image. The analysis was based on plots between different physical parameters like axial dimensions and volume determined by both the methods. The mass of tomato was also predicted on the basis of volume.

Statistical analysis: The statistical analysis was performed using Descriptive Statistics at 95% confidence level for mean in Microsoft Excel 2007. The paired t-test and the Bland-

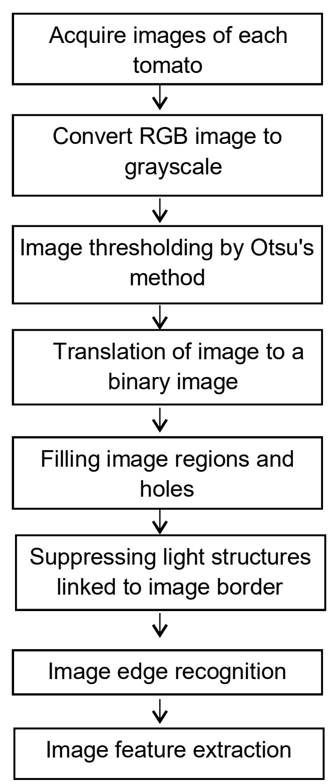

Fig. 1. Flow diagram for image processing and analysis

Altman plots (the mean difference confidence interval approach) were used to compare the engineering characteristics determined by image processing technique and the standard method. The paired t-test was used to test the significance of difference between the two measurements. A correlation was developed between parameters measured by both the methods. The Bland-Altman approach was used to plot the agreement between the values measured by both the methods.

RESULTS AND DISCUSSION

Tomato fruits of variety *Punjab Chhuhara* were separated into six grades viz. Grade A (30-34 mm), Grade B (35-39 mm), Grade C (40-46 mm), Grade D (47-56 mm), Grade E (57-66 mm) and Grade F (67-81 mm). A total of 150 fruits were evaluated for each parameter. The length of the tomato fruit was considered as the major criteria for grading categories. The length of tomato fruits varied (mm) between 30.00-33.99, 35.04-39.23, 40.19-46.00 48.17-55.90, 57.34-65.85 and 67.11-79.48 for grades A, B, C, D, E and F respectively. The true volume of different grades of tomato was determined using water displacement method (Table 1). The true volume of smallest grade of tomato was 4666 mm^3 whereas it was 38760 mm^3 for largest grade.

Linear relationship was observed between calculated volume and true volume for ellipsoid shape of tomatoes (Fig. 2). In addition to this, the value of R^2 for all the samples of tomatoes of respective grades was greater than 0.9. This was in agreement with by Kumar et al (2013) for selected dry beans. Therefore, both the methods of volume measurement i.e. either by using equivalent diameter or by the three different axial dimensions can be used successfully. The percent change in volume was 89.74, 5.41, - 30.61, - 135.43, - 57.89 and - 68.1 for respective grades. The negative values indicated that calculated volume was higher as compared to that of true volume.

Engineering parameters of tomato by image processing: The physical properties of tomato fruits were also extracted from images with the help of MATLAB software. The parameters like major axis diameter, minor axis diameter, equivalent diameter were extracted from the images. The fruit images were calibrated by taking images of a black colour square sheet of size 5cm x 5cms from the standard height i.e. 160 mm selected for tomato mm.

For tomato, 1mm = 17 pixels

The volume calculated from the images of tomato (longitudinal and lateral view) of different grades also showed correlation with the measured true volume (Fig. 3). The value of R^2 for respective grades was observed to be 0.814, 0.915, 0.910, 0.971, 0.893 and 0.963 for longitudinal view and 0.907, 0.920, 0.897, 0.969, 0.961 and 0.932 for lateral view. The relationship between the volumes of overall tomato measured with both the methods was also developed and is shown in Figure 4. The value of R^2 was 0.923.

Bland-Altman plot of mean values and differences of volumes for tomato obtained by image processing method and water displacement method were also plotted to check the agreement between both the methods (Fig. 5). The volumes determined by both the methods for tomato were normally distributed and was M = 14438.01 mm^3 (95% confidence interval). The 95% limits of agreement for comparison of volumes for tomato measured with both the methods were e -4848.25 mm^3 and 33724.27 mm^3 (Fig. 5).

The same pattern was observed by Khojastehnazhand et al (2009) for oranges, Rashidi et al (2007) for kiwifruit volume and Soltani et al (2010) for banana volumes. The paired samples t-test results showed that volume obtained with image processing method was not significantly different from the parameters measured with water displacement method for tomato (Table 2). Hence the images of tomato captured

Table 1. Volume of different tomato grades

Characteristics	Grade A (30-34 mm)	Grade B (35-39 mm)	Grade C (40-46 mm)	Grade D (47-56 mm)	Grade E (57-66 mm)	Grade F (67-81 mm)
Volume of ellipsoid tomato (mm^3)						
Mean	65010.15	78455.96	123993.80	210424.60	324000.10	500562.50
Standard deviation	12174.01	16944.40	30896.90	46718.50	83630.18	88059.16
True volume (mm^3)						
Mean	4666.67	11777.78	11779.00	12207.00	25170.00	38760.00
Standard deviation	2135.30	5341.41	3030.17	4042.89	4324.54	9283.02

Table 2. Paired sample t-test analyses on a comparison of volume measurement methods for tomato

Parameter	Size	Average difference (mm^3)	Standard deviation of difference (mm^3)	P value	95% confidence intervals for the difference in means (mm^3)
Tomato	150	6879.79	5249.52	0.723	6031.98, 7727.61

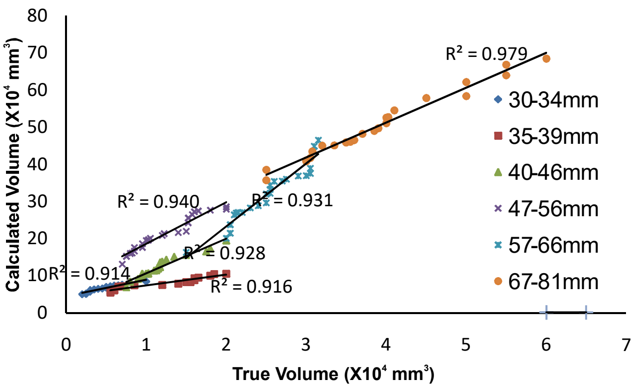

Fig. 2. Relationship between true volume and calculated volume for ellipsoid shape of tomato

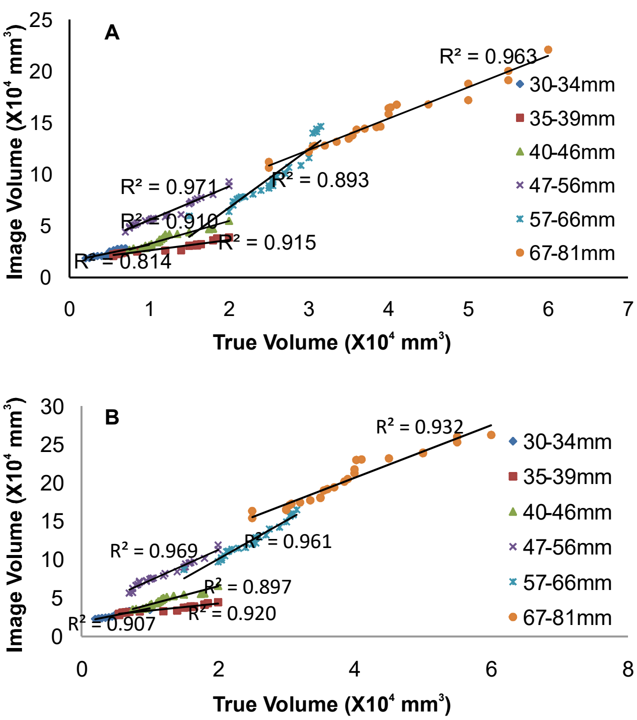

Fig. 3. Relationship between true volume and volume worked from images of different grades of tomato (a) Longitudinal view (b) Lateral view

with digital camera can be efficiently used for the study of geometrical properties.

Prediction of mass based on volume: The connection between mass of the fruits and the volume estimated by both water displacement and image processing method was also studied (Fig. 6). The R^2 for water displacement method was 0.971 whereas was 0.984 for volume determined by image processing method. The volume and mass are highly correlated. The same result was obtained by Omid et al (2010) while estimating mass and volume of citrus fruits

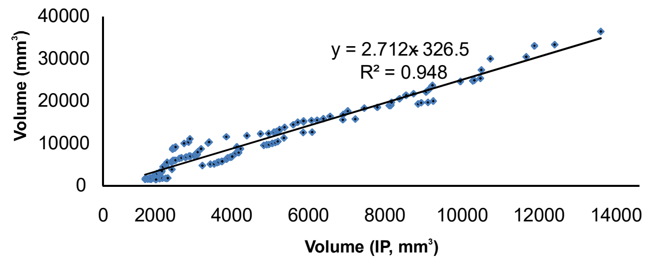

Fig. 4. Relationship between the volume of tomato measured with water displacement method and calculated from image

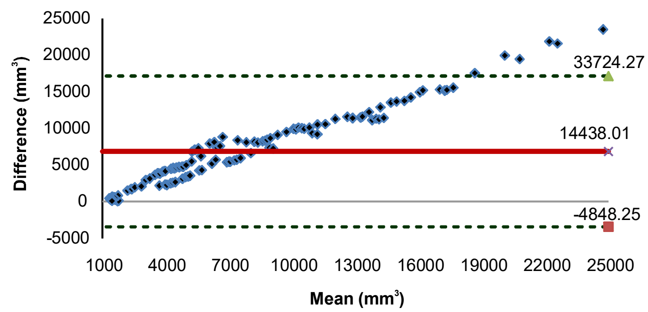

Fig. 5. Bland-Altman plot for the assessment of volume of tomato computed with image processing (IP) method and measured by water displacement method

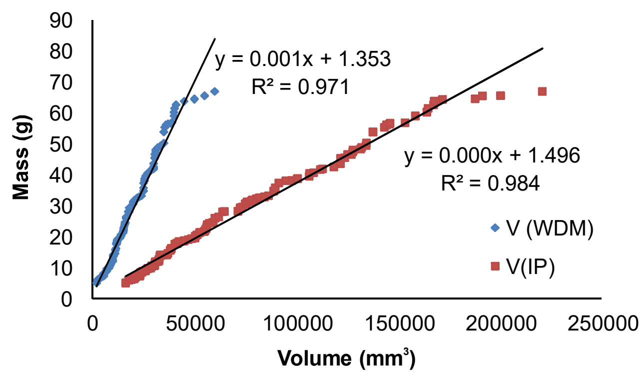

Fig. 6. Relationship between mass and volume of tomato

using image processing. The data was concluded to be best fit for mass determination based on volume of fruit using image processing technique.

CONCLUSIONS

The two methods were presented for estimating the volume of tomatoes. Both the methods were relatively general and may be applied for volume calculation of other ellipsoidal agricultural crops such as peaches, eggs, onion, lemons and kiwifruit etc. The volume calculated from the images of different grades of tomato showed good correlation with the volume measured by water displacement method. Also, the results for various tomato fruits showed that the volume and mass are highly correlated. Mass can be predicted easily using image processing data. The paired samples t-test results showed that parameters determined by image processing method was not significantly (P>0.05) different from the those measured using vernier caliper. This information can be used to design and develop sizing systems.

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Impact of Change in Temperature on Yield and Water Requirement of Winter Maize using FAO-AquaCrop Model for North Bihar

Vipin Chandan, Ravish Chandra* and Manish Kumar

Department of SWE, CAET, Dr. Rajendra Prasad Central Agricultural University
Pusa, Samastipur-848 125, India
**E-mail: ravish@rpcau.ac.in*

Abstract: The simulation analysis was made for three *winter* seasons 2016-17,2017-18 and 2018-19 and for five levels of maximum and minimum temperature increase and compared with the performance of *winter* maize crop with actual temperature level using the FAO-Aquacrop model. The five levels of maximum and minimum temperature increases were T_{max}+1°C, T_{max}+2°C, T_{max}+3°C,T_{max}+4°C, T_{max}+5°C and $T_{min.}$+1°C, T_{min}+2°C, T_{min}+3°C,T_{min}+4°C, T_{min}+5 °C respectively. For *winter maize*, model prediction for the future temperature increases in maximum temperature for five levels T_{max}+1°C, T_{max}+2°C, T_{max}+3 °C,T_{max}+4°C, T_{max}+5 °C showed a positive response on simulated crop yield and biomass. The increase in yield and biomass of *winter* maize varied from 5.6 to 23.7 % for 2016-17, 4.3 to 19.6 % for 2017-18 and 6.4 to 27.3 % for 2018-19 for five levels of temperature increase T_{max}+1°C, T_{max}+2°C, T_{max}+3°C,T_{max}+4°C, T_{max}+5°C respectively. The average increase in simulated yield and biomass of *winter* maize was found to be 3.73 % for 2016-17, 3.06 % for 2017-18 and 4.19 % for 2018-19 for one degree (1°C) rise in maximum temperature. Model prediction for the future temperature increase in minimum temperature for five levels also showed a positive response on simulated crop yield and biomass. But the predicted yield and biomass increase are more pronounced in case of increase due to maximum temperature elevation. The average increase in simulated yield and biomass of *winter* maize was found 4.07 % for 2016-17, 3.37 % for 2017-18 and 4.47 % for 2018-19 for one degree (1°C) increase in minimum temperature. Crop water requirement increased with increasing level of maximum temperature for all three years. With the increase in temperature simulated yield also increased for winter maize alongside crop water requirement.

Keywords: Aquacrop model, Winter maize, Simulation model, Crop water requirement, IPCC

Water is an important resource for all life forms and will become a scarce natural resource in the future due to climate variability/change. Climate change has become very important for the farming sector in India. The persistent dry seasons and floods threaten the sustenance of billions of individuals who rely on land for their future requirements. Relationships between crop, climate, water and soil are complicated and many biological, physiological, physical and chemical processes are involved. These changes occur with average warming of just 1.1 degrees C (1.98 degrees F) above pre-industrial levels. The IPCC sixth assessment report reveals that the world is likely to reach or exceed 1.5 degrees Celsius (2.7 degrees Fahrenheit) of warming in just the next two decades (IPCC Sixth Assessment Report 2021). Global warming has been observed over the past decades and is consistently associated with changes in various components of the water cycle and hydrological systems, such as: Climate change Precipitation patterns, intensity and extremes; increased atmospheric water vapor; increased evaporation; and changes in soil moisture and runoff.

Maize (*Zea mays* L.) is a significant crop of the globe with the highest production and profitability when compared with rice and wheat, possessing an area of 193 m ha with a creation of 1147 m tonnes and mean productivity of 5.92 t ha^{-1} (FAOSTAT, 2018). Maize positions 3rd among grain crops in India after rice and wheat, with a region of 9.47 million hectares, with a production of 28.72 m tones (Directorate of Economics Statistics 2017-18). There are three distinct seasons for the cultivation of maize in India: *Kharif* , *Rabi* in Peninsular India and Bihar, and *Spring* in northern India. Bihar is a significant maize-producing state, accounting for approximately 6.6 % of total national maize production, with nearly 0.65 million hectares of maize planted each year. *Winte*r maize is grown on a land area of 0.46 million hectares, with a grain production of 1.86 million tonnes and a normal yield of 4.1 t/ha in 2020-21 (Ministry of Agriculture & Farmers Welfare, Govt. of India-ON2930). Winter maize in Bihar state has a larger region with a normal productivity of 4.1 t/ha and Autumn*/kharif* maize with a normal productivity of 2.85 t/ha. There is a big difference between potential and actual grain yield of *winter* maize in Bihar and growth and yield largely depends on climatic factors such as temperature, rainfall etc. that prevails during the crop growth period. FAO- Aquacrop model can be useful in evaluating the impact of climate change on crop yield and biomass for winter maize. Aquacrop models have been successfully used for simulating growth and yield parameters of various crops (Kumar and Chandra 2018, Chandra et al 2021, Chandra and Kumari 2021). The precipitation during *winter* is very deficient for the effective development of high-yielding maize hybrids. Actually, ideal accessibility of assured irrigation water is one among the central point deciding the accomplishment of the yield. Therefore, there is a need for proper management of existing water resources and the development of future water resources. Keeping the importance of climate change and its impact on crop growth and water requirement the present investigation was undertaken with the objective of study of impact of the increase in maximum and minimum temperature on crop growth, yield and crop water requirement of *winter* maize using FAO-AquaCrop model.

MATERIAL AND METHODS

The study on "Assessment of impact of climate change on water requirement and yield of winter maize using FAO-Aquacrop model for Pusa, Bihar." was conducted during *winter* season for the three years 2016-17, 2017-18 and 2018-19. The present investigation was conducted with a view to estimate the effect of rise in temperature on yield, biomass and crop water requirement of *winter* maize using FAO Aquacrop model. The present study was extended to simulate *winter* maize yield, biomass and crop water requirement using latest version FAO- Aquacrop model (version 6.1) under climate change scenario.

Study area: The study region is situated at *Pusa* block of Samastipur district of North Bihar (Fig. 1). The investigation area is encircled by southern and western bank of the waterway Burhi Gandak at 25°59'N latitude and 85°48'E longitude. The elevation above (MSL) is 52.92 m.

Climatic condition: The study area has the humid sub-tropical atmosphere, which is significantly affected by south-west rainstorm. The normal precipitation of the region is 1276 mm out of which almost 1026 mm is received during the storm between June to September. Winter showers infrequently happen in this district from December to the main portion of January. The blistering climate begins from early March and it lasts up to the end of May. The mean maximum average temperature May-June ranges between 37.5°C to 40.6°C and the mean minimum average temperature for the period varies from 17.0°C to 21.8°C.

Aquacrop model: AquaCrop is a crop growth model developed by the Land and Water Division of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

Different scenario for simulation: To assess future climate change impact analysis, the changed scenario of increasing maximum temperature by 1, 2, 3, 4 and 5^{0}C was studied. The daily maximum temperature was increased by 1, 2, 3, 4 and 5^{0}C and keeping the other parameters same the yield, biomass and water requirement was simulated. Similarly, the daily minimum temperature was increased by 1, 2, 3, 4 and 5^{0}C and keeping the other parameters same the yield, biomass and water requirement were simulated. Table 1 displays the different scenario of increased maximum temperature. The simulation model was run for three years 2016-17, 2017-18 and 2018-19.

Crop parameters adopted for the Study: The crop input component of AquaCrop contains both user-specific and conservative parameters, which can be categorized into crop parameters, phenology, development, and water stress groups).Crop data input for the FAO-Aquacrop model are

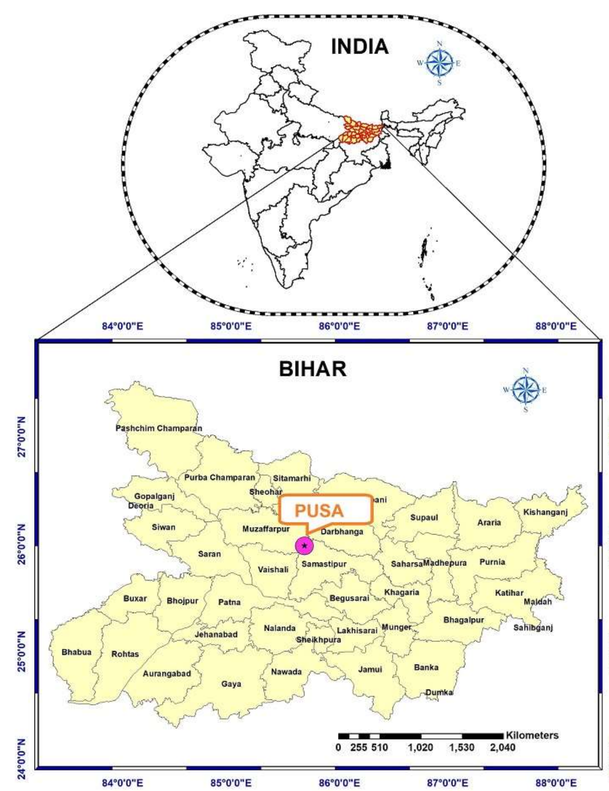

Fig. 1. Map of study area

plant density, emergence time, canopy senescence and maturity time, flowering period and yield formation duration, rooting depth, and reference HI, duration of crop, irrigation water management and agronomic practices. FAO-AquaCrop uses less crop parameters that describe the plant physiological and growth attributes. The crop parameters for winter maize were adopted from Kumar and Chandra 2018.

RESULTS AND DISCUSSION

Effect of increase in maximum temperature on simulated crop yield and biomass: The simulation analysis was made for three *winter* seasons 2016-17,2017-18 and 2018-19 and for five levels of maximum temperature increase and compared with the performance of *winter* maize crop with actual temperature level. The simulated crop yield and biomass increases as maximum temperature increases (Table 2). The simulated studies for *winter* maize revealed an increase in crop yield from baseline for all the three winter seasons. The increase in simulated yield and biomass for winter season 2016-17, 2017-18 and 2018-19 ranged from 5.6 to 23.7, 4.3 to19.6 and 6.4 to 27.3 %, respectively (Table 2). The increase in simulated yield and biomass was most prominent for the year 2018-19. The increase in maximum temperature is actually helping the *winter* maize to perform

Table 1. Different Scenario with increased maximum and minimum temperature for winter maize

2016-17	2017-18	2018-19
Tmax. +0°/Tmin. + 0°	Tmax. +0°/Tmin. + 0°	Tmax. +0°/Tmin. + 0°
Tmax. +1°/Tmin. + 1°	Tmax. +1°/Tmin. + 1°	Tmax. +1°/Tmin. + 1°
Tmax. +2°/Tmin. + 2°	Tmax. +2°/Tmin. + 2°	Tmax. +2°/Tmin. + 2°
Tmax. +3°/Tmin. + 3°	Tmax. +3°/Tmin. + 3°	Tmax. +3°/Tmin. + 3°
Tmax. +4°/Tmin. + 4°	Tmax. +4°/Tmin. + 4°	Tmax. +4°/Tmin. + 4°
Tmax. +5°/Tmin. + 5°	Tmax. +5°/Tmin. + 5°	Tmax. +5°/Tmin. + 5°

Table 2. Effect of change in maximum temperature on simulated crop yield and biomass of winter maize during crop growing season

Weather parameter (Maximum temperature)	Crop yield (t ha^{-1})	% increment	Biomass (t ha^{-1})	% increment
2016-17				
$T_{max.}$ +0°C	10.52	-	21.91	-
T_{max}+1°C	11.11	5.60	23.14	5.61
T_{max}+2°C	11.66	10.83	24.30	10.90
T_{max}+3°C	12.17	15.68	25.35	15.70
T_{max}+4°C	12.62	19.96	26.30	20.03
T_{max}+5°C	13.01	23.66	27.10	23.68
2017-18				
$T_{max.}$ +0°C	10.07	-	22.09	-
T_{max}+1°C	10.51	4.36	23.04	4.30
T_{max}+2°C	10.93	8.54	23.96	8.46
T_{max}+3°C	11.32	12.41	24.83	12.40
T_{max}+4°C	11.70	16.18	25.65	16.11
T_{max}+5°C	12.05	19.66	26.42	19.60
2018-19				
$T_{max.}$ +0°C	10.64	-	22.16	-
T_{max}+1°C	11.32	6.39	23.59	6.45
T_{max}+2°C	11.97	12.50	24.94	12.54
T_{max}+3°C	12.57	18.13	26.20	18.23
T_{max}+4°C	13.10	23.12	27.29	23.14
T_{max}+5°C	13.55	27.34	28.23	27.39

better. If the comparison is made between three distinct *winter* seasons of different years it is evident from the analysis that increases in simulated yield and biomass is lesser for the year 2017-18 compared to 2016-17 and 2018-19. The actual mean maximum temperature for the f January in the winter season 2017-18 was 26.8^{0}C compared to 22.4^{0}C and 22.8^{0}C for winter season 2016-17 and 2018-19 respectively. The threshold temperature set for winter maize was 30^{0}C and with an increase in temperature up to 5^{0}C particularly for the year 2017-18. The simulated yield gain was lower compared to 2016-17 and 2017-18. In climate change scenario rise in maximum temperature might prove beneficial for winter maize during three growing seasons of 2016-17, 2017-18 and 2018-19. The similar results have been reported by Chabra and Haris (2014). In winter maize season, model prediction for the future temperature increase shows a positive response with increase in maximum temperature by 1,2,3,4 and 5^{0}C. However positive response becomes less sensitive with increase in maximum temperature 4-5^{0}C. The high-quality yield response is probably because of growth in thermal time as temperature decided plant growth. The higher temperature has simulated the photosynthetic procedure resulting in higher simulated yield. The study area experiences low maximum temperature during winter season and rise in maximum temperature might be proving beneficial to the crop. The increase in yield is attributed to positive effect of comparatively high minimum temperature for winter maize crop. This may be because of decline in damaging impact of low temperature on crop during development stages.

Effect of increase in minimum temperature on simulated crop yield and biomass: The percentage increase in simulated crop yield and biomass for five levels of increase in minimum temperature i.e., $T_{min.}$+1^{0}C to T_{min}+5 ^{0}C were 5.8 to 26.1 % for 2016-17, 9.9 to 26.8 % for 2017-18 and 6.6 to 28.9 % for 2018-19.In winter season, the model prediction for the increasing level of minimum temperature shows a positive response. The percentage increase in crop yield was higher for 2018-19 compared to 2016-17 and 2017-18. The average minimum temperature during January, February and March for the year 2018-19 was lower compared to the other two seasons which might may be due to higher

Table 3. Effect of change in minimum temperature on simulated crop yield and biomass of winter maize during crop growing season

Weather parameter (Minimum temperature)	Winter maize			
	Crop yield (t ha^{-1})	Increment (%)	Biomass (t ha^{-1})	Increment (%)
2016-17				
$T_{min.}$+0^{0}C	10.52	-	21.91	-
T_{min}+1^{0}C	11.13	5.79	23.18	5.79
T_{min}+2^{0}C	11.71	11.31	24.40	11.36
T_{min}+3^{0}C	12.27	16.63	25.56	16.65
T_{min}+4^{0}C	12.79	21.65	26.65	21.65
T_{min}+5^{0}C	13.27	26.14	27.65	26.19
2017-18				
$T_{min.}$+0^{0}C	10.07	-	22.09	-
T_{min}+1^{0}C	11.07	9.93	23.07	4.43
T_{min}+2^{0}C	11.52	14.39	24.00	8.64
T_{min}+3^{0}C	11.96	18.76	24.91	12.76
T_{min}+4^{0}C	12.37	22.84	25.77	16.65
Tmin+5^{0}C	12.77	26.81	26.60	20.41
2018-19				
$T_{min.}$+0^{0}C	10.64	-	22.16	-
T_{min}+1^{0}C	11.34	6.57	23.63	6.63
T_{min}+2^{0}C	12.01	12.87	25.02	12.90
T_{min}+3^{0}C	12.64	18.79	26.34	18.86
T_{min}+4^{0}C	13.21	24.15	27.53	24.23
Tmin+5^{0}C	13.72	28.94	28.59	29.01

percentage of increase for the year 2018-19 compared to other two seasons. The positive yield reaction may be because of an increment in thermal time just as an increment in temperature decided plant development. The higher temperature might have invigorated photosynthetic cycles and harvest improvement and brought about higher recreated yield. The minimum temperature increase has responded more positively than the maximum temperature increases of winter maize. The better temperature regime has simulated photosynthetic procedure which brought about higher simulated yield.

Response of increase in maximum temperature on crop water requirement: The crop water requirement increase as maximum temperature increases (Table 4). The analysis of the data revealed that crop water requirement is increasing with increasing level of maximum temperature for all three years and with increase in temperature simulated yield also increased for winter maize but crop water requirement also increased. The percentage increase in crop water requirement for five levels of increase in maximum temperature i.e., T_{max}+1^{0}C to T_{max}+5 ^{0}C varied from 2.0 to 10.9 % for 2016-17, Similarly 2017-18 and 2018-19 varied from 1.9 to 10.4 % and 2.2 to 10.6 % respectively. Parekh and Prajapati (2018) and Chowdary and Abbas (2016) also observed similar trend.

Table 4. Effect of change in maximum temperature on crop water requirement of winter maize during crop growing seasons

Weather parameter (Maximum temperature)	Crop water requirement (mm)	increase (%)
2016-17		
$T_{max.}$ +0^{0}C	334.10	-
T_{max}+1^{0}C	340.80	2.00
T_{max}+2^{0}C	347.90	4.13
T_{max}+3^{0}C	355.40	6.37
T_{max}+4^{0}C	359.90	7.72
T_{max}+5^{0}C	370.50	10.89
2017-18		
$T_{max.}$ +0^{0}C	327.30	-
T_{max}+1^{0}C	333.80	1.98
T_{max}+2^{0}C	339.90	3.84
T_{max}+3^{0}C	348.00	6.32
T_{max}+4^{0}C	354.50	8.31
T_{max} +5^{0}C	361.50	10.44
2018-19		
$T_{max.}$ +0^{0}C	338.90	-
T_{max}+1^{0}C	346.10	2.21
T_{max}+2^{0}C	352.80	4.10
T_{max}+3^{0}C	360.00	6.22
T_{max}+4^{0}C	367.60	8.47
T_{max} +5^{0}C	375.00	10.65

CONCLUSIONS

The FAO-Aqucrop model was used to predict the response of increase in maximum and minimum temperature on yield, biomass and crop water requirement of *rabi* maize crop for *Pusa* region for three seasons. The effect of change of maximum and minimum temperature up to + 5^{0}C on simulated crop yield and biomass of *rabi* maize was analyzed. For *rabi* maize, model prediction for the future temperature increases in maximum temperature for five levels T_{max}+1^{0}C, T_{max}+2 ^{0}C, T_{max}+3 ^{0}C,T_{max}+4^{0}C, T_{max}+5 ^{0}C showed a positive response on simulated crop yield and biomass. However positive response is more sensitive for T_{max}+1^{0}C, T_{max}+2 ^{0}C, T_{max}+3^{0}C and becomes less sensitive with increase in maximum temperature by 4-5 ^{0}C (T_{max}+4^{0}C, T_{max}+5^{0}C).Model prediction for the future temperature increase in minimum temperature for five levels $T_{min.}$+1^{0}C, T_{min}+2^{0}C, T_{min}+3^{0}C,T_{min}+4^{0}C, T_{min}+5 ^{0}C also showed a positive response on simulated crop yield and biomass. But the predicted yield and biomass increase are more pronounced than the increase due to maximum temperature elevation. Crop water requirement increased with increasing level of maximum temperature for all three years. With increase in temperature, simulated yield and crop water requirement, both, increased for winter maize. The FAO-Aqucrop model can be used effectively to estimate the agricultural crop water requirement, crop yield and irrigation scheduling for different crops for North Bihar conditions under changing climatic scenario.

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Laboratory Investigation on Rotary Impact Cutter Blade Parameters for Multistep Cutting of Paddy Straw

Abhishek Patel, Krishna Pratap Singh and Ajay Kumar Roul

ICAR-Central Institute of Agricultural Engineering, Bhopal-462 038, India
E-mail: abhishekpatel2910@gmail.com

Abstract: The present study focused on the laboratory evaluation and optimization of the chopping unit of straw chopper cum mixture machine for paddy straw management. During the study a laboratory setup was developed for simulating the cutting process of counter-rotating blades of a chopper for cutting of paddy straw. The effect of operational parameters i.e., blade type, rotational and forward speed of the machine, and crop parameters i.e. days after harvesting (DAH) on the power requirement was observed. The response surface methodology was used to develop a statistical model to predict the torque requirement for chopping straw by front attachment of the rotary tiller. The developed model was optimized in order to minimize power required during chopping operation. The results of study showed that the cutting torque was significantly ($p \leq 0.05$) affected by the rotational speed, forward speed and DAH of the paddy straw. A straw management system (SMS) serrated blade operating at rotational and forward speed of 900 rev. min^{-1} and 1 $km.h^{-1}$ respectively with average cutting torque of 3.8 N-m was found to be optimal for cutting the paddy straw. The paddy straw chopping performed after 1-2 DAH requires minimum power. Hence, it was concluded that the optimized chopping system can be effectively used as cutting unit in rice straw incorporator.

Keywords: Blade optimization, Crop residue management, Rice straw, Straw incorporation

Rice (*Oryza sativa* L.) is one of the most important staple food, feeding more than 50% of the global population. Combine harvester leaves loose rice straw on the ground, making its collection and transportation difficult, laborious and costly. Annually, about 600 to 800 million tons of rice straw are produced in Asia; globally approximately 1 billion tons are produced. In India, 697 million metric tons of crop residue was generated from 26 crops. Approximately 60 to 70% of farmers prefer to burn the residue whereas, less than 1% of farmers incorporate in order to prepare the field for sowing of next crop. Due to a lesser window period during sowing of wheat and harvesting of rice crop, farmers choose to burn the rice residue in the field (Verma et al 2016). Rice residue collection and transportation makes ex-situ residue management economically unfeasible (Parihar et al 2023). Straw incorporation is a common practice to improve soil fertility and the yield of paddy. In general, residue retention promotes soil health, reduces soil erosion, improves soil water content and enhances crop productivity.

Paddy straw was managed using different practices such as bailing, collection and incorporated into the field (Ramulu et al 2018). Machinery like Happy seeder, zero till drill, spatial till drill, smart seeder and super seeder were popular among the farmers which results as a lack of adoption these technologies due to lack of knowledge and higher cost of the machinery (Parihar et al 2022). Generally, above said machines works horizontal shaft-based crop residue choppers with flails were commonly used to reduce the crop residues length and incorporated into the soil. The chopping blade and its design have a significant effect on crop straw chopping quality, power consumption and its operational life (Fu et al 2011). The hammer blades, straight blades and bent blades (Y-shaped and L-shaped) (Liu, 2012) are some of the commercially available blades for chopping paddy straw. The arrangement of the blade also has a significant effect on the performance and operational reliability of the straw chopper. Mountings of the blades on the rotor improves the chopping quality and helps for balancing of the straw chopper. The most commonly used blade arrangements are helical, symmetrical and staggered (Bao et al 2016).

Several researchers have developed flail type blade system in order to chop different kinds of crop residues. Manes et al (2016) introduced a trail-type chopper that has a cutting unit with flail blades to harvest the paddy straw and a chopping unit with fixed blades to chop straw delivered by the cutting unit. Zhang (2014) designed a fixed-blade cylindrical straw chopper that has the functions of paddy straw pickup, cutting, stubble cleaning and soil incorporation. Li and Li (2001) also studied the blade arrangement by comparing the behavior of rotor dynamic balance to reduce the vibration of the straw chopper. Based on the literature cited above it can be seen that the most of the paddy straw chopping systems having a flails type blade which seems to impart excessive vibration and noise during working (Ji et al 2003, Tu et al

2003). It was also seen that very limited scientific data is available on the vertical shaft mounted blades used for chopping of paddy straw. Therefore, present study was formulated to study the different blade types i.e. SMS serrated, cutter bar and SMS plain blade mounted on vertical shaft and operating at different rotational and forward speeds for the paddy straw samples taken at different DAH, through laboratory experiments. The parameters under study were optimized and selection of blade in order to minimize the torque requirement.

MATERIAL AND METHODS

The paddy straw (*c.v. Kranti*) used in this work was provided by the ICAR-CIAE Bhopal. The straw bunch from the field was collected on three different days after harvesting of paddy by the combine harvester. Paddy straw bunches with a height of 35-40 cm were placed over the bunch holder for experimentation. The experiments were conducted on the same day (M_1), fifth day (M_2) and tenth day (M_3) after harvesting, respectively. The moisture content of the paddy straw was 35 (M_1), 26 (M_2) and 17% (M_3) for 0, 5 and 10 DAH, respectively.

Experimental setup: The CAD model of the laboratory setup for cutting torque measurement was drawn in CREO 3.0 software as shown in Figure 1. The laboratory setup required for the simulation and prediction of cutting torque to cut the paddy straw is shown in Figure 2. The developed chopping unit consisted of two vertical counter-rotating shafts, each having a pair of flanges with four blades. The blades were equally spaced in the flange. The cutting width was 340 mm for a single rotor, therefore the total cutting width was 630 mm with an overlapping of 50 mm was provided between two rotors. The mechanism had horizontal and vertical adjustments.

The present research work carried out in an indoor soil bin consists of a tool carriage trolley, linear movement transmission system and data logging system. Even though the soil was not a part of this experimental study, it was used to keep the straw bunch holder in front of the tool carriage system and can easily be controlled by the control panel during the cutting process.

An AC motor (3.7 kW) was used to supply the power required for the blade through a V-belt pulley mechanism. The motor had a double V groove pulley to accommodate two V belts for both shafts. One shaft was connected directly while the other was connected in cross belt for the counter-rotation mechanism of the setup. The chopped paddy straw was pushed inwards by counter rotation of blades. A torque transducer (HBM T22/kNm) was connected on the AC motor shaft to measure the torque required to cut the paddy straw (Fig. 1). The data was recorded using HBM data logger (MX840B, 8 channel). The straw bunch holding device was made of MS flat with a circular pipe of diameter 40 mm and was welded at a space of 200 mm between the two bunches. Similarly, three rows were fabricated to hold the bunches. The rotating and forward speeds of the designed cutting setup were controlled using the control panel.

Experimental design: An optimization study was conducted for selection of suitable cutting blade for paddy straw cutting unit. Three different types of blades namely SMS serrated, cutter bar and SMS plain blades with a thickness of 4 mm were used in this study. The independent parameters used in this study were forward speed, rotational speed and moisture content (M_1, M_2, and M_3) in terms of days after harvesting. The Central Composite Rotatable Design (CCRD) along with Response surface methodology (RSM) was used for optimization of machine and operational parameters. The minimum and maximum values for these variables were selected after the preliminary experiments. The range of rotational speed and forward speeds were between 500 to 900 rev/min and 1 to 2 $km.h^{-1}$, respectively. A total of 48 experimental combinations were obtained for each type of blade by conducting six experiments at the center point and replicating three times at factorial and axial points. The statistical analysis in this study was done using Design-Expert software (version 13.1). The sequential model sum of squares (SMSS), lack of fit test and coefficient of determination (R^2) were considered for selection of an appropriate model. In numerical optimization, the solution was obtained as a point with maximum desirability.

The selection of blade was done based on the minimum cutting torque measured by the torque sensor for cutting paddy straw. The frictional torque produced during idle operation of the setup prior to and during each experiment was added to calculate the actual torque required for cutting the straw. The effect of design factors on the response parameters was evaluated using analysis of variance and regression analysis with a second-order polynomial model. Paired t-test was used for validating the predicted model value.

Total power requirement: The total power requirement for the cutting of the straw bunch was calculated according to the given equation 1 & 2. It is the combination of frictional and cutting power which was corresponding to the frictional (T_f) and cutting torque (T_c).

$$T_t = T_f + T_c \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$P = \frac{2 \times \pi \times N \times T_t}{60} \quad \ldots\ldots (2)$$

Where, P = power, Watt; N = blade rotation per mint; T = cutting torque, Nm,

RESULTS AND DISCUSSION

The actual torque required to cut the paddy straw versus time is shown in Figure 4. The figure showed that the SMS serrated blade has a very less cutting torque (12.25 Nm) than the cutter bar blade (17.67 Nm) followed by SMS plain blade (20.01 Nm).

The quadratic model was selected and all the models were significant (Table 1). The models were capable to represent the variability of the data set to capture the effect of design factors over the response parameters. The lack of fit was found non-significant indicating the model efficiently estimated the response parameters. The cutting torque obtained from the blades A, B and C through the test runs during the experiment and the predicted values accessed by quadratic models followed linear relationship. The curve indicates a good fit to the model and it sufficiently covers the design factors within the experimental range. The deviation of observed and estimated straw cutting torque values was found to be acceptable and a good agreement with R^2 values 0.99, 0.97, and 0.95, respectively indicates the accuracy of the selected models.

Effect of operating parameters on cutting torque for different types of cutting blades: The forward speed, blade rotational speed and days after harvesting have significant effect on the cutting torque for all types of blades. The cutting torque increased significantly as the forward speed increased for all types of blades whereas it decreased as the rotational speed increased and decreased with increase in days after harvesting. The increase of forward speed and DAH, cutting torque increased from 4.5 to 6.7 Nm (Fig. 5). It may be due to the interacting time being less at high forward speed (Sahoo and Raheman 2020). The increase in days after harvesting (DAH) from 0 to 10 days the cutting torque also increased from 6.06 to 8.64 Nm because of the reduction in moisture content of the straw. At the same time, the increment in rotational speed of the blade from 500 to 900 rev/min caused a reduction in cutting torque from 7.1 to 5.5 Nm. It may be due to high impact when the rotational speed increased, the stems were cut without flattening or crushing with a low resistive force from the paddy stem. The cutting process was accomplished by a large resistive force from the paddy stems with flattening and crushing at lower rotational

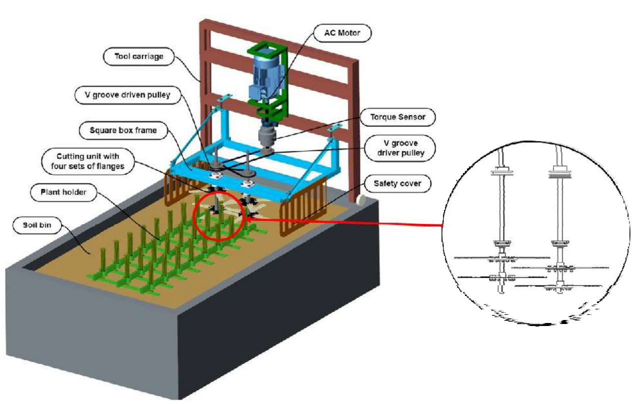

Fig. 1. Detailed specification of cutting torque setup representation by CAD model

Fig. 2. a) Laboratory setup for cutting torque measurement, Paddy straw bunch in plant holder (b) before cutting and (c) after cutting

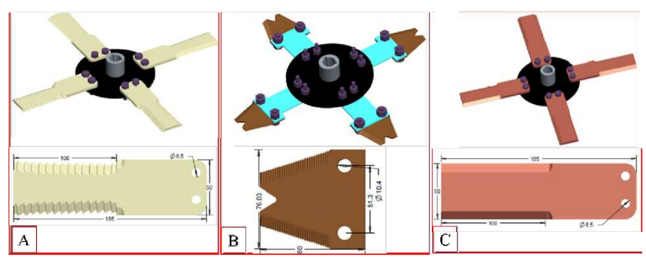

Fig. 3. Placement and dimensions of different blades A) SMS Serrated, B) Cutter bar and C) SMS Plain blade

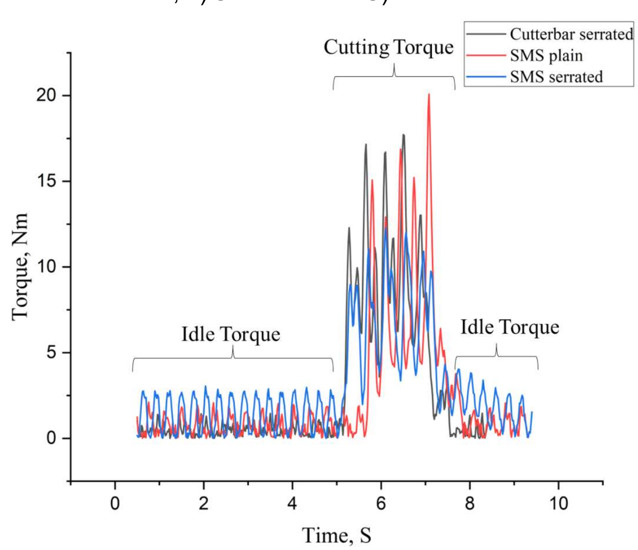

Fig. 4. Torque v/s travel time curve for different blade

speeds. The influence of each parameter on the cutting torque required by the SMS serrated blade was less followed by the cutter bar and the SMS plain blade.

Combined effect of independent parameters on the cutting torque: The combined effect of independent parameters on the response was observed from the 3D response surface plots (Error: Reference source not found) by keeping the third value at the center point. The blue and red color shows the minimum and maximum values of cutting torque. The regression analysis revealed that cutting torque was significantly affected by the interaction of independent parameters. The cutting torque of all three types of blades were greatly affected by the interactions between forward and rotational speed as well as the rotational speed with DAH.

SMS serrated blade: The cutting torque was increased constantly from 5.6 to 7.2 Nm with an increase in forward speed from 1 to 2 km h^{-1} at a constant rotational speed of 500 rev/min whereas, it decreased from 5.6 to 3.8 Nm by increasing rotational speed 500 to 900 rev/min at a forward speed of 2 km h^{-1} (Fig. 5A). Lower forward speed of 1 km.h^{-1} and maximum rotation of blade 900 rev/min had minimum

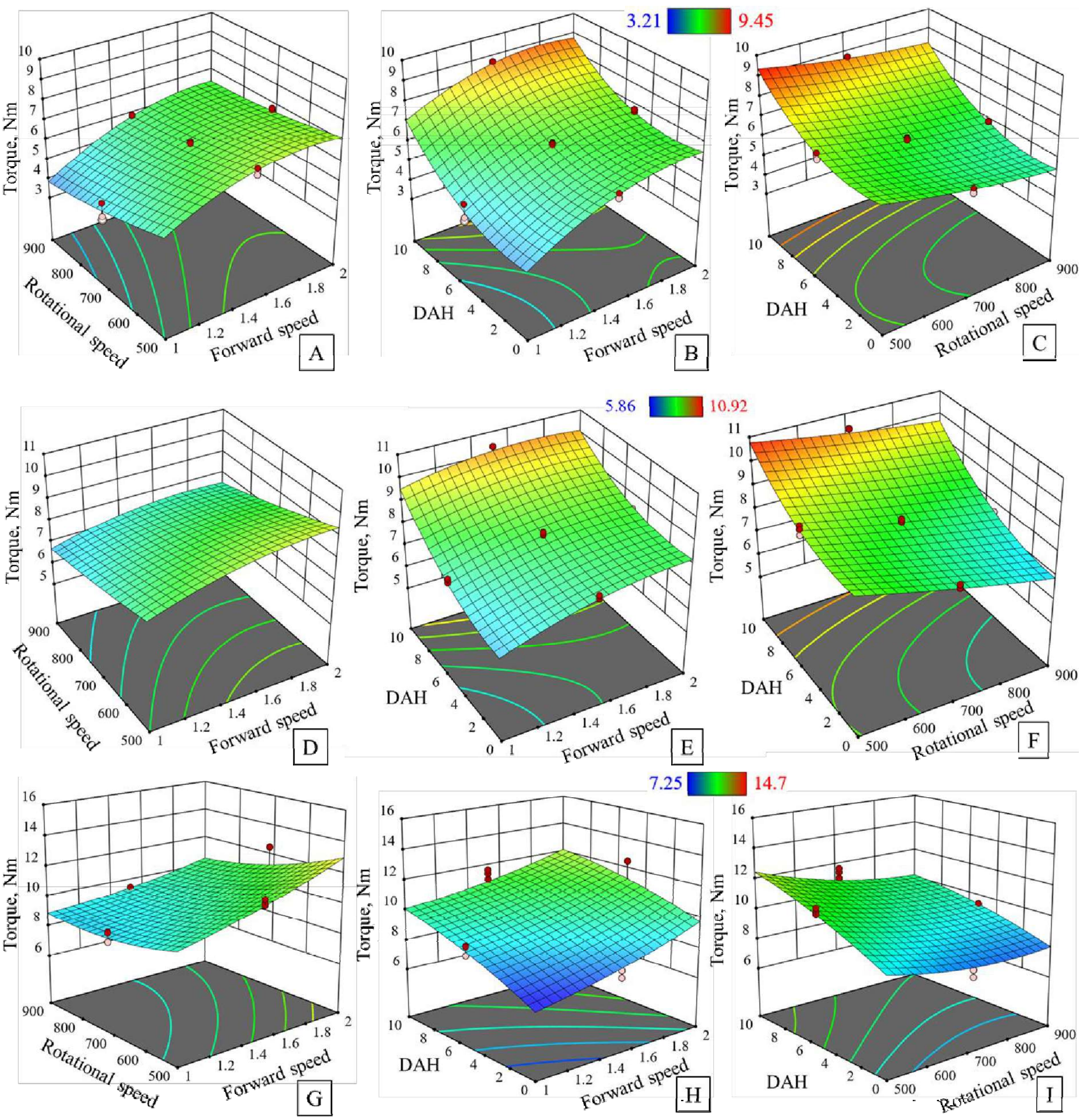

Fig. 5. Response surface curve for cutting torque by SMS serrated (A, B, C), cutter bar (D, E, F) and SMS plain (G, H, I) blade

cutting torque of 3.8 Nm. Interaction effect of forward speed and DAH (Error: Reference source not found B) by keeping the third parameter fixed in-between values, the cutting torque was minimum (4.1 Nm) and increased up to 6.6 Nm at forward speed from 1 to 2 km h^{-1} at 0 DAH, whereas in extreme values of the parameter (2 km h^{-1} forward speed and 10 DAH) cutting torque was maximum 8.89 Nm. Similarly in the interaction of DAH and rotational speed (Error: Reference source not found C) by keeping the forward speed constant at mid value, the cutting torque was decreased from 6.9 to 5.5 Nm at 0 DAH, whereas the cutting torque increased from 6.9 to 9.5 Nm at 500 rev/min for increase in DAH from 0 to 10, respectively.

Cutter bar blade: The cutting torque was increased constantly from 8.2 to 9.5 Nm with an increase in forward speed 1 to 2 km.h^{-1} at a rotational speed of 500 rev/min whereas, it decreased from 8.1 to 7.0 Nm by increasing rotational speed 500 to 900 rev/min at a forward speed of 2 km.h^{-1} (Error: Reference source not found D). At a lower forward speed of 1 km h^{-1} and a maximum rotation of blade 900 rev/min had minimum cutting torque. Interaction effect of forward speed and DAH (Error: Reference source not foundE) by keeping the third parameter fixed in-between values, the cutting torque was minimum 6.7 and increases up to 8.2 Nm at forward speed from 1 to 2 km h^{-1} at 0 DAH, whereas in extreme values of parameter (2 km h^{-1} forward speed and 10 DAH) the cutting torque was maximum of 10.1 Nm. Similarly in the interaction of DAH and rotational speed by keeping the forward speed kept fixed at mid value, the cutting torque was decreased from 8.8 to 6.9 Nm at 0 DAH, whereas at constant 500 rev/min the cutting torque increased from 8.8 to 10.7 Nm in the variable range of DAH from 0 to 10, respectively.

Table 1. Analysis of variance of different types of blades for cutting torque

Source	df	F-value		
		SMS Serrated	Cutter bar	SMS plain
Model	9	436.48*	190.03*	75.10*
Forward speed (A)	1	1184.51*	189.92*	225.92*
Rotational speed (B)	1	453.70*	404.75*	103.07*
DAH (C)	1	1807.04*	951.46*	292.17*
AB	1	53.34*	8.37*	21.56*
AC	1	39.63*	31.38*	5.13**
BC	1	8.42*	28.22*	11.28*
A²	1	152.61*	23.50*	2.81 NS
B²	1	8.53*	1.11 NS	9.02*
C²	1	291.05*	79.35*	4.03 NS
Lack of Fit	5	1.21NS	2.13 NS	2.45 NS
R^2	-	0.99	0.97	0.95
CV, %	-	2.51	2.46	4.46

* = Significant at p≤ 0.01, ** = Significant at p≤ 0.05, NS= Non-significant, df= degree of freedom, R^2= coefficient of determination, CV= coefficient of variance

SMS plain blade: The cutting torque was increased constantly from 9.7 to 12.8 Nm with an increase in forward speed from 1 to 2 km h^{-1} at 500 rev/min whereas, it decreased from 9.7 to 8.8 Nm by increasing rotational speed from 500 to 900 rev/min at a forward speed of 2 km.h^{-1} (Fig. 5G-I). The cutting torque was minimum at the forward speed of 1 km.h^{-1} and the blade rotations of 900 rev/min. Interaction effect of forward speed and DAH (Error: Reference source not found H) by keeping the third parameter fixed in between range, the cutting torque was minimum 6.9 Nm and increased up to 9.7 Nm at forward speed of 1 to 2 km.h^{-1} at 0 DAH, whereas in extreme values of the parameter (2 km.h^{-1} forward speed and 10 DAH) cutting torque was maximum of 12.2 Nm. Similarly in the interaction of DAH and rotational speed (Error: Reference source not foundI) by keeping the forward speed kept fixed at mid-value in the range of the variable, the cutting torque was decreased from 9.0 to 7.9 Nm at 0 DAH, whereas at constant 500 rev/min, the cutting torque increased from 9.0 to 12.4 Nm in the variable range of DAH from 0 to 10, respectively.

Total power requirement: The power required for cutting of paddy straw by different types of blades was calculated by Eq. 2 and determined the effect of rotational speed on cutting power (Fig. 6). The result showed a good agreement between the rotational speed of the blade and cutting power with an R^2 value greater than 0.9. As the rotational speed of

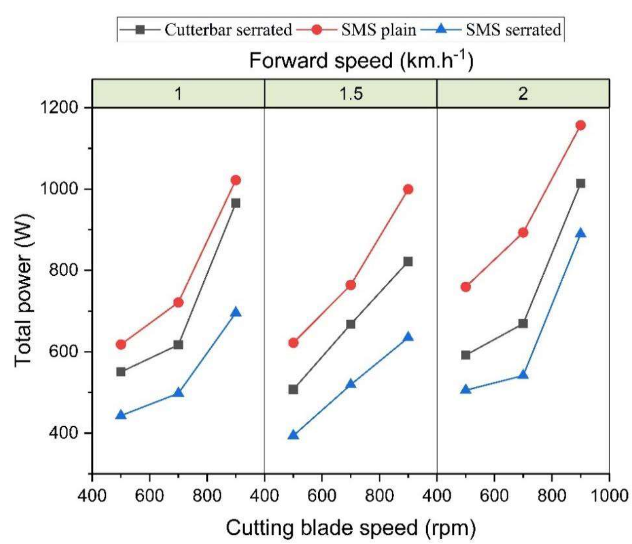

Fig. 6. Total cutting power vs. cutting blade rev/min at a different rotational speed

Table 2. Optimized values of selected SMS serrated blade of design parameters and responses

Design parameters	Goal	Lower	Upper	Optimum value
Forward speed, km.h^{-1}	in range	1	2	1
Rotational speed, rev/min	in range	500	900	900
DAH	in range	0	10	1.24
Torque (Response)	minimize	3.21	9.45	3.214

Table 3. Model validation using paired t-test for cutting torque for SMS serrated blade

Response	Predicted	Actual value ± SD	Standard error	Mean difference	t_{cal}
Torque, Nm	3.21	3.26 ± 0.52	0.03	0.045	0.271

h_0: $\mu_0 = \mu_1$, $t_{cal} < t_{tab}$ at p<0.01, h0 was accepted

the blade increased from 500 to 900 rev/min, the power requirement also increased and thereafter reduced within the variable range in all blade types and results followed the study of Sahoo & Raheman (2020). In the present study, a minimum cutting power of 0.62 kW requirement was observed in the SMS serrated blade and hence, it was selected for the optimization of design variables.

The increase in forward speed from 1 to 2 km h^{-1} and rotational speed from 500 to 900 rev/min, the total cutting power was also increased. There was a significant effect on the total power of the three blades when rotational speed varying from 500 to 900 rpm at 1 km.h^{-1} forward speed. The SMS serrated blade required less power to cut the paddy straw than the cutter bar followed by the SMS plain blade. Similarly, the increasing trend of total power requirement was observed for all three blades with a change in forward speed and rotational speed from 1.5 to 2 km h^{-1} and 500 to 900 rev/min, respectively. It was concluded from the Figure 6 that the total power was minimum at a forward speed of 1 km h^{-1} followed by 1.5 and 2 km h^{-1}. It may be due to the amount of paddy straw chopped would be less at a forward speed of 1 km h^{-1} compared to 1.5 and 2 km h^{-1}.

Optimization and model validation: The constraints range of different independent parameters with optimized values are shown in Table 2. The minimization of torque required was the target while optimizing the parameters. The optimization of the selected blade was carried out based on the input parameters such as rotational speed, forward speed, and DAH. The numerically optimized results had a desirability of 0.98 when a second order model equation was used. A two-tailed t-test was used to compare the model projected value to the actual values under the optimization settings, which indicates no significant difference (Table 3). The the established model to forecast the responses of cutting the paddy straw by SMS serrated blade can be used after harvesting along with the specified design parameters.

CONCLUSION

The operational parameters had a significant effect on the torque and power requirement for the cutting purpose. A minimum torque of 3.8 N-m and total cutting power of 0.62 kW were observed at 900 rev/min on the 0th DAH for the SMS serrated blade followed by the cutter bar and SMS plain blade for cutting the paddy straw. The validation of the developed model to estimate the torque required for the cutting of paddy straw exhibit a good agreement between the actual and estimated torque with an accepted R^2 value. The rotational speed should be more than 700 rev/min for the effective cutting of paddy crops, whereas, the forward speed should be within 1.5 km.h^{-1} to obtain a proper cutting quality with minimum torque. The study will help in selection of suitable blade with optimized operational parameters for development of an efficient cutting system of chopping cum incorporation unit for in situ management of paddy straw.

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Assessment of Wastewater Quality Discharged from Common Effluent Treatment Plant (CETP) and its Impact on Irrigated Soil around Jajmau, Kanpur, India

Bhanu Pratap and Venkatesh Dutta

Department of Environmental Science, School of Earth and Environmental Sciences
Babasaheb Bhimrao Ambedkar University, Lucknow-226 025, India
E-mail: bhanu791bbau@gmail.com

Abstract: The present study is undertaken to assess the concentration of heavy metals (Cu, Cd, Cr, Zn, Fe, Ni, Mn and Pb) in treated wastewater discharged from the Common Effluent Treatment Plants (CETPs) and in the wastewater-irrigated soil around Jajmau in Kanpur, Uttar Pradesh. The wastewater irrigation applied for a long time had a severe effect on irrigated soil and human health. High concentrations of HMs were reported both in collected wastewater samples (Fe>Zn>Mn>Cr>Cu>Cd>Ni>Pb) and soil samples (Fe>Zn>Cr>Cu>Ni>Mn>Pb>Cd) from the agriculture fields. The physicochemical characteristics of wastewater are analyzed using parameters such as color, pH, temperature, BOD, COD, TDS, EC, TN, sulfate, phosphate, potassium and chloride. For the assessment of the physicochemical properties of soil, pH, soil texture, soil moisture, EC, SOM, TOC, available nitrogen, available sulfate, available phosphorus and available potassium were considered. The study will be beneficial for providing the theoretical and statistical data to support wastewater treatment and the merits and demerits of reusing wastewater for irrigation. The outcome is also important in view of the safe and sustainable use of treated wastewater for irrigation, reducing the pressure on freshwater resources and supporting the growth of agriculture while protecting public health and the environment.

Keywords: Wastewater irrigation, Reuse, Farmers profile, Physicochemical characteristics, Soil properties, Heavy metals

Freshwater is not only a valuable natural resource that maintains the survival and development of society but is also considered an essential element of the ecosystem (Smol et al 2020). Worldwide, due to the massive scale of industrialization, urbanization and increasing population, freshwater resources are declining rapidly. Therefore, the situation needs urgent action to scale up efforts in restoration, recycling and reuse to lessen the existing load on freshwater resources (Pratap et al 2023). The recycling and reuse of treated wastewater for agriculture production reduces the demand for freshwater that needs to be extracted from natural resources (EPA 2012, Pratap et al 2021). Over 97% of all the water on earth's surface is saline present in the oceans and the remaining 3% is available as freshwater. Considering accessible freshwater, out of this only 1% is available for human consumption in the form of groundwater, rivers, lakes, streams and reservoirs and the rest 2% is frozen in the form of polar ice caps (Angelakis et al 2021). Due to improper treatment and disposal facilities, most of the industrial effluents are discharged without appropriate treatment processes into the nearby waterbodies or passed through unlined channels resulting in the contamination of freshwater resources. In the past, many developed countries have understood the strategic significance of wastewater recycling and reuse. In 1973, World Health Organization (WHO) published health guidelines for the safe use of wastewater for agricultural irrigation which initiated the application of treated wastewater for irrigation that should be followed strictly (WHO 2006). The Food and Agriculture Organization (FAO) has also issued two technical reports about wastewater treatment and irrigation and effluent quality control on the basis of the current situation of wastewater irrigation worldwide (FAO 1992, Pratap et al 2023).

As a vast agricultural country, India's agriculture sector consumes an extensive amount of freshwater, accounting for more than 70% of the total freshwater consumption. Although India accounts for only 2.2% of the global land, it has 4% of the world's water resources and 16% of the world's population (Pratap et al 2021). Unfortunately, in India, the state of Uttar Pradesh alone is discharging more than half of the heavy metals (HMs) into rivers and streams, with partial or untreated effluent discharged into them. Kanpur, one of the biggest mechanical and business-focused industrial hubs in northern India, has over 800 industries involved in the manufacturing of goods and products. The industrial area of Jajmau in Kanpur alone has more than 400 tanneries engaged in chrome tanning processes and is home to the biggest manufacturer of leather footwear and leather goods (Gupta et al 2018). According to estimates, about 80-90% of tanneries use chromium sulfate in tanning processes, which generates large volumes of toxic effluents that require advanced treatment processes. Tannery wastewater is heavily contaminated with high levels of HMs such as copper, cadmium, chromium, zinc, iron, nickel, manganese, and lead. Although a Common Effluent Treatment Plant (CETP) operates to treat industrial effluent, the treated effluent has been continuously used for irrigation of nearby farming lands for the last four decades. The wastewater-irrigated area covers around 1800 hectares of agricultural land and approximately 10 villages. The long-time application of wastewater irrigation has contaminated the irrigated soil and crops by a huge margin. By consuming these crops, serious health hazards have been reported among consumers (Gupta et al 2018). It has been previously stated by CLRI, Madras (Central Leather Research Institute) that a single tannery can cause pollution of groundwater around a radius of 7 to 8 km (CLRI 1990). Discharged effluent if allowed to percolate into the soil to the groundwater for a long-time could seriously affect the soil profile and the groundwater of the locality making it unfit for drinking, bathing, irrigation and other uses (Mukherjee et al 2020). So, the objectives of this study are to assess the quality of discharged effluent and its suitability for irrigation purposes in reference to the physicochemical properties of effluent and irrigated soil. The present study also deals with the application of wastewater irrigation and its effects on human and environmental health. These specific objectives are designed to promote the sustainable application of wastewater irrigation in India and provide theoretical and statistical support by reusing through high-efficiency treatment of wastewater.

MATERIAL AND METHODS

Site description: The selected site is located on the right bank of the Ganga River at Jajmau (26º24′22″ N latitude and 80º26′12″ E longitude) in Kanpur, U.P. India and is chronically polluted with HMs. A number of industrial units such as tanneries, leather manufacturing industries, cotton and textile mills, chemicals, paints, plastics, fertilizers and arms manufacturing factories are situated there. Specifically, Kanpur is one of the biggest exporting centers of tanned leather of the Ganga alluvial plain. A Common Effluent Treatment Plant (CETP) is situated in the Jajmau area that receives wastewater from the cluster of industrial units located around it. The wastewater treatment is carried out throughout the year and discharged effluents were conveyed to farms through an 8 km long canal where farmers reuse this wastewater for crop irrigation. From this long canal, farmers have made different branches of small canals and diverted them into their agricultural land. Surface irrigation method applied by the farmers for the irrigation of their crops in which wastewater is distributed over the soil surface by the open flow. At the selected site mainly cereals (rice and wheat) and vegetables (potato, onion, beetroot, cabbage, spinach, cauliflower and mustard) crops are grown by the farmers. The study site is situated in the humid subtropical climatic zone and the year is divided into three seasons: the winter season (November-February), the summer season (March-June) and the monsoon season (July-October).

Collection of wastewater and soil samples: The wastewater and soil samples were collected from the selected sites at regular intervals of 30, 60 and 90 days. Wastewater samples were collected in clean plastic containers (5 l) and soil samples were collected from horizon 'A' soil profile (0-20cm depth) which is usually contaminated with HMs. The collected wastewater samples were immediately brought to the laboratory, stored at 4ºC and used for the physicochemical and HMs analysis. The soil samples were collected in self-locking, double-sealed polythene bags and carried to the laboratory for further analysis. Soil samples were oven dried for two days at 70°C and finely powdered and sieved into 250 mm mesh size for physicochemical and HMs analysis. It is seen that the analytical values are above the standard range of certified values of reference materials.

Physicochemical (PC) characteristics and HMs analysis of wastewater and soil samples: The collected wastewater samples were analyzed in three replicates for physicochemical characterization to define the pollution profile of wastewater as per the standard protocols outlined in the Standard Methods for Examination of Water and Wastewater (APHA 2017). Collected soil samples were air-dried, ground to pass through a 2 mm size sieve and stored in plastic bags for further analysis. The samples were analyzed for different physicochemical properties as per the standard procedure. The soil pH was estimated by pH meter in the saturation medium as described by McNeal 1983. The same saturation medium was used for the estimation of electrical conductivity using a conductivity meter. Soil organic matter was estimated by the Walkley-Black method (Jackson 1967). Available nitrogen was estimated by the Kjeldahl method (Bremner and Mulvaney 1982) and available sulfate and phosphorous were determined by Olsen's method using a UV-visible spectrophotometer (Olsen and Sommers 1982). Available potassium was estimated by using a flame photometer as per the standard method. Furthermore, the Inductively Coupled Plasma Mass-Spectrophotometer (ICP-MS) was used for the detection of HMs (Cu, Cd, Cr, Zn, Fe, Ni, Mn and Pb) in collected wastewater and soil samples (Table 1).

Statistical analysis: All the experimental data were statistically analyzed using MS Excel software and the mean of three values was calculated against the critical difference (CD) at a 5% level of significance.

Quality control and quality assurance: According to the Environmental Protection Agency (EPA), the samples for heavy metals were ensured for the analytical quality data through repeated analysis (n=3) (EPA 2012). The experiment was performed for three months and wastewater and soil samples were collected randomly from the selected sites. All the collected samples were analyzed in three replicates and the reported values are the mean of three replicates ±SE.

RESULTS AND DISCUSSION

Farmers' profile: Most of the farmers in the study area are not much aware of the possible health and environmental impacts of wastewater irrigation. This may be followed due to the lack of alternative irrigation water resources and easy accessibility of wastewater. Most of the interviewed farmers were male but some females were also involved in agricultural practices. The literacy rate of the farmers being interviewed was very low and most of them did not know about the health impacts of wastewater irrigation. The age of survey respondents was between 20 to 60 years and most of them were about 40-50 years old. Farmers had similar views about the history of reusing wastewater for irrigation and the majority (60-70%) of them reported that they have been using wastewater for irrigation for the last four decades. The results of this study indicate that a low literacy rate and lack of information among the farmers could be the main reasons behind the application of untreated and partially treated wastewater for irrigation.

Physicochemical characteristics of wastewater samples: The physicochemical parameters such as color, pH, temperature, biochemical oxygen demand (BOD),

Table 1. Physico-chemical characterization of wastewater and soil samples

Parameters	30 days	60 Days	90 days
Wastewater			
Color	Black	Black	Black
pH	8.13±0.06	8.03±0.15	8.17±0.06
Temperature	27.33±0.58	29.67±0.58	32.33±0.58
BOD (mg L^{-1})	261.00±4.58	274.67±4.04	289.67±4.51
COD (mg L^{-1})	931.33±5.69	980.33±6.66	993.67±3.21
TDS (mg L^{-1})	279±2.08	238.33±3.06	229.67±4.51
EC (mS/cm)	0.56±0.00	0.48±0.01	0.46±0.01
Total Nitrogen (mg L^{-1})	221.33 ±6.02	256.66±4.16	274.33±4.50
Sulfate (mg L^{-1})	1232.33±7.63	1260.33±6.02	1278.33±5.03
Phosphate (mg L^{-1})	513.66±5.03	531.66±5.50	554.33±7.02
Potassium (mg L^{-1})	165.33±3.05	174.33±3.51	181.33±2.08
Chloride (mg L^{-1})	116.33±2.51	122.33±3.51	126.33±3.05
Soil			
pH	8.03±0.12	8.07±0.15	8.10±0.10
Sand (%)	54.00±1.00	54.33±0.58	56.00±1.00
Silt (%)	32.67±0.58	33.67±1.15	35.00±1.00
Clay (%)	14.00±1.00	13.67±2.08	9.00±1.00
Moisture (%)	77.48±0.65	73.59±0.45	71.65±1.40
EC (mS/cm)	2.03±0.01	3.08±0.05	3.05±0.9
SOM (%)	1.11±0.03	1.25±0.06	1.34±0.05
TOC (%)	2.12±0.03	1.96±0.06	2.21±0.02
Available Nitrogen (mg kg^{-1})	2.17±0.03	2.25±0.03	2.35±0.04
Available Sulphate (mg kg^{-1})	9.13±0.02	9.27±0.06	9.44±0.09
Available Phosphorus (mg kg^{-1})	4.16±0.03	5.13±0.05	5.28±0.06
Available Potassium (mg kg^{-1})	7.34±0.05	7.43±0.15	7.55±0.09

± Standard Deviation

chemical oxygen demand (COD), total dissolved solids (TDS), electrical conductivity (EC), total nitrogen (TN), sulfate, phosphate, potassium, and chloride of wastewater was measured which showed that the wastewater irrigation applied for a long time had a severe effect on irrigated soil and human health (Table 1).

Physicochemical characteristics of soil samples: Long-term wastewater irrigation and the presence of reported HMs clearly indicate that the discharged effluent is not suitable for the irrigation of soil. The worst thing is that these elements have been far beyond the ability of soil self-purification causing serious pollution and changes in soil physicochemical characteristics. The pH of collected soil samples was found to be alkaline between the range of 8.32-8.10. Once the pH value varies drastically, the soil physicochemical properties would be changed accordingly which affects the existing composition and availability of soil nutrients directly. The availability of soil organic matter is not only related to natural environmental conditions but also depends on the supply of organic matter through irrigated wastewater. Available nitrogen, available sulfate, available phosphorus and available potassium had significantly increased because of long-term wastewater irrigation that accumulated in the upper soil layer (0-20 cm) (Table. 1). Available nitrogen is an essential nutrient for crop growth and the continuous supply of nitrogen with wastewater affects soil productivity.

Heavy metals concentration in different wastewater samples: Interviewed farmers showed concerns about the hazards of wastewater irrigation. Further, analytical results showed the presence of HMs above the acceptable limits in wastewater and their bioaccumulation in soil systems. Particularly Cr, Zn, Fe, Ni, Mn and Pb were found in wastewater samples above the permissible limits (Fig. 1) (WHO 2006). Higher concentrations of HMs in collected wastewater samples might be the outcome of treated or partially treated industrial effluents discharged by CETP and its application for growing crops over a long period that has built up HMs in the soil systems.

Heavy metal concentration in soil samples: Long-term wastewater irrigation results in HMs contamination of soil up to a toxic level which in turn leads to the degradation of soil productivity. This concentrations of HMs higher than the recommended permissible limits in collected soil samples irrigated with wastewater. However, the severity of wastewater irrigation depends on its source, composition, treatment before use and management at the farm levels. Very high concentrations of Fe, Zn, Cr and Cu were in the collected soil samples (Fig. 2) (WHO 2006). Higher concentrations of HMs were observed in the upper soil layers of the selected locations (0-20 cm). Physicochemical properties such as soil pH, texture, EC and SOM play a great role in HMs contamination of wastewater-irrigated soil. In general, long-term wastewater irrigation would be responsible for the adsorption of HMs in soil particles resulting in soil HMs pollution which has become the most serious hazard for human health and the environment. Ultimately, these HMs are dangerous to human health through various food chains.

The long-term application of wastewater irrigation may alter the physicochemical properties and microbiota of irrigated soil which may further deteriorate land fertility and crop productivity. The physicochemical analysis of wastewater and soil samples of this study has revealed that the pH and EC values were higher due to the presence of a high concentration of organic and inorganic salts. Several other findings reported the threats of wastewater irrigation and their impacts on the soil profile by affecting pH, salinity, nutrient availability, organic matter content and microbial diversity (Jaramillo and Restrepo 2017, Pratap et al 2021). The continuous practice of wastewater irrigation resulted in the accumulation of HMs in the irrigated soil and subsequently in crops growing therein (Shahid et al 2017).

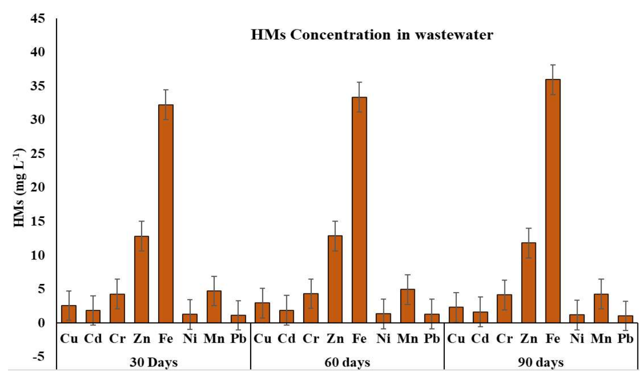

Fig. 1. Heavy metals concentration in collected wastewater samples

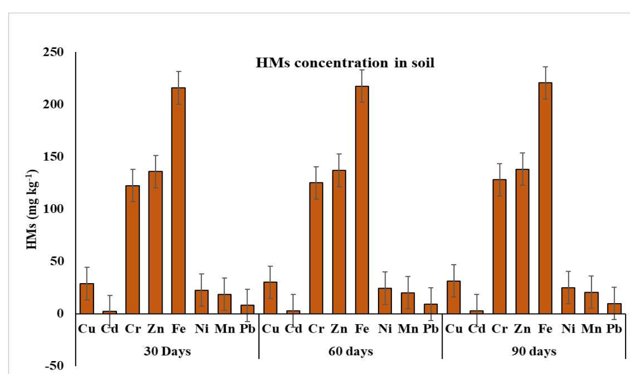

Fig. 2. Heavy metals concentration in collected soil samples

The high concentration of HMs (above the permissible limit) is mainly due to the condensation process which takes place during the tanning process in tannery industries. Reuse of this wastewater for crop irrigation leads to health risks to farmers and consumers via food chain and the environment. The transfer of HMs from wastewater to irrigated soil primarily via the absorption process. The absorption of HMs such as Fe, Zn, Cr and Cu within soil depends upon pH, temperature, organic matter, nutrient availability and available moisture content (Wang et al 2017, Pratap et al 2021).

A study carried out on wastewater irrigation through the polluted water of Musi River at Hyderabad, Telangana, India, showed the translocation of HMs at different trophic levels (Qadir et al 2010). The arid and semi-arid northern and central part of Mexico uses reclaimed wastewater to irrigate their crops. Moreover, the Tula Valley, one of the largest areas of the world covering more than 90,000 hectares of agricultural land is using treated wastewater for agricultural production (Navarro et al 2015). In India, several regions reuse treated or partially treated wastewater for the irrigation of agricultural crops. Finally, the exposure of HMs from crops to human beings takes place directly via dietary intake of wastewater-irrigated crops, especially green vegetables (Woldetsadik et al 2017). Previous studies indicated that wastewater irrigation resulted in serious hazards for the environment such as HMs pollution of the soil and groundwater. Long-term wastewater irrigation may significantly affect the groundwater through leakage of salty and HMs-rich wastewater making them unfit for human consumption (Jaramillo and Restrepo 2017, Pratap et al 2021). They can cause serious threats to human health if used for drinking, cooking and domestic purposes. HMs could also enter into freshwater bodies through runoff and potentially affect aquatic ecosystems (Pratap et al 2023). This study may be useful in planning a safe cropping system for such HMs-contaminated agricultural fields as well as the management and safe disposal of such wastewater to avoid contamination of fertile agricultural fields. Reusing treated wastewater in India for the irrigation of more than 1.5 million hectares of agricultural land annually could reduce the pressure on freshwater resources. However, recycled wastewater also carries adverse effects on soil and crops, the environment and human health. Therefore, continuous improvement in wastewater treatment technologies and stricter monitoring approaches are urgently required to promote reuse of treated wastewater for crop irrigation in India (Qadir et al 2010, Pratap et al 2021).

CONCLUSIONS

The specific objectives have been designed to promote the sustainable application of wastewater irrigation in India and provide theoretical and statistical support for the reuse of wastewater through high-efficiency treatment. The idea is to (a) encourage the adoption of advanced treatment technologies for efficient and effective wastewater treatment, (b) create awareness among farmers and the local community about the safe and sustainable use of treated wastewater for irrigation, (c) assess the quality of treated wastewater and its impact on soil, crops, and groundwater, (d) identify potential health risks associated with the use of untreated or partially treated wastewater for irrigation, and (e) develop guidelines and regulations for the safe and sustainable use of treated wastewater for irrigation. In India, encountering the problems of water scarcity and the high cost of fertilizers, wastewater could be used for irrigation. Starting from the sources of wastewater generation, the quality aspect should be considered strictly at treatment plants which could strengthen the quality of discharged wastewater. For the individual, the health risks of wastewater irrigation should be extensively published enhancing awareness of environmental and human health hazards. The reuse of wastewater for irrigation practices has gained importance worldwide due to limited water resources and the very high cost of wastewater treatment technologies. Wastewater contains a high amount of organic matter, nutrients and HMs which are toxic to soil, crops and human health beyond a certain limit. The indiscriminate long-term use of wastewater for crop production could result in HMs contamination that may become hazardous for the farmers and consumers. Wastewater-irrigated soil may accumulate HMs in sufficient amounts to cause chronic diseases in farmers and local people who have been consuming these HMs accumulated crops. Results indicate that the reuse of wastewater with appropriate treatment processes could increase the water resources for irrigation which may be beneficial for agricultural production. Therefore, wastewater irrigation needs to consider the actual situation at selected sites carefully and strict treatment protocols should be considered to achieve safe and effective reuse of wastewater for irrigation.

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Morphometric Analysis using Geospatial Techniques to Infer Hydrologic Behaviour of Waghadi Watershed, Maharashtra, India

Arti Kumari, Pramod Tiwary[1], Ashutosh Upadhyaya and Pawan Jeet

Division of Land and Water Management, ICAR-Research Complex for Eastern Region, Patna-800 014. India
[1]Division of Soil Resource Studies (SRS) ICAR- ICAR- NBSS & LUP, Nagpur-440 033, India
E-mail: kumariarti995@gmail.com

Abstract: An attempt was made for morphometric analysis using geospatial techniques to study hydrologic behaviour of Waghadi watershed, Maharashtra, India, which helps in decision making regarding implementation of water conservation and management plan. In the study area, SRTM-DEM data was used to generate drainage network and slope map in Arc GIS environment. Results revealed that the drainage pattern of the study area showed dentritic to subdendritic, coarse drainage texture in nature along with 6^{th} order streams. The values of form factor (0.28), circulatory ratio (0.37) and elongation ratio (0.6) showed elongated shape with mean bifurcation ratio (5.92) represented strong structural control over the drainage pattern. Majority of its area is agricultural land (55%), followed by forest (39%), and comprises primarily of hydrologic soil groups C and D, which have moderate to high runoff potential zones and are the ideal from harvesting surface runoff point of view. However, most of area has a gentle to moderate slope (3-5%) while the upper and boundary regions are mostly hilly, with moderate steep to very steep slopes >35%, helps in allocation of various water harvesting structures. Such type of study exemplifies how remote sensing and GIS may be used to water harvesting planning.

Keywords: Geospatial Techniques, Hydrologic responses, Morphometric analysis, Maharashtra, Waghadi watershed

Globally, the current imbalance between water availability and demand is a primary apprehension, and India is not an exception. In our county, total average water resource potential is to be 1869 BCM, with just 690 BCM being usable. Similarly, the available replenishable ground water is 432 BCM, of which 342 BCM is usable (CWC 2016-17). Rising water shortage issues create a severe challenge to societal sustainability, environmental management, and economic growth. Apart from that, climate change manifestations in the form of severe weather conditions have exacerbated these problems. Due to significant climate fluctuation, drought has long been endemic in semi-arid region states of the country such as Rajasthan, Andhra Pradesh, Karnataka, Maharashtra and Gujarat etc. Maharashtra's agriculture is its lifeblood but the agricultural sector's growth has been inconsistent, and it has been significantly reliant on highly variable rainfall throughout the year. This circumstance highlights the necessity for the government to focus not only on increasing gross state domestic product (GSDP) development in the agriculture sector, but also on reducing variability in growth through better water resource management. The ideal unit for management of these natural resources is watershed. However, water resource development/management requires an assessment of the watershed's hydrologic response based on morphometric analysis. Watershed morphometry refers to shape, size, and configuration of the earth's surface and landforms (Clarke 1996, Agarwal 1998, Reddy et al 2002). Linear, aerial, and relief aspects have been studied in the morphometric analysis in GIS environment (Agarwal 1998). The morphological analysis is a valuable tool for studying a catchment's topography and hydrological condition (Pirasteh et al 2010). It also gives useful criteria for determining groundwater potential zones, identification of suitable sites for water harvesting structures, geographic characteristics and so on (Aher et al 2014, Malik et al 2019a, Rathore et al 2022). Recently, the use of remote sensing and GIS techniques to compute morphological characteristics has proven to be less time-consuming, rapid, and precise, resulting in the best spatial representation of topographic circumstances (Singh et al 2013, Gautam et al 2021). However, it is also helpful for implementing soil and water conservation treatments at the watershed scale. Several scholars who conducted morphometric analysis by geospatial methodologies indicated that detailed and up-to-date drainage basin information may be created in a systematic way (Aparna et al 2015, Ayele et al 2017, Farhan et al 2017, Gizachew and Berhan, 2018, Gutema et al 2017, Javed et al 2009, Kulkarni, 2013, Magesh et al 2012, Pande and Moharir, 2017, Prakash et al 2016, Rai et al 2017, Singh et al 2014, Singh et al 2008, Soni, 2017, Asfaw and Workineh 2019). Their findings provide essential hydrogeologic, erosion-prone, and watershed features in terms of ground and surface water potential. Morphometric analysis also helps to deal with major environmental challenges such as slope instability, flooding, landslides, and extreme surface runoff at various scales like river basin, watersheds etc. (Biswas et al 1999, Kumar et al 2000, Nag and Chakraborty 2003, Vittala et al 2004, Chopra et al 2005, Conforti et al 2011, Dinagara Pandi et al 2017, Magan et al 2019). Even though, this is an established well-known fact, still there is paucity of detailed studies regarding hydrologic response of Waghadi watershed, Maharashtra. However, the study area situated in yavatmal district where water security is jeopardised by improper location of water harvesting and recharging structures as well as their poor operation and maintenance issues (Kumar and Sen, 2021). Along with it, there is rapid declination of ground water up to 4 m in study area (CGWB, 2017-18). Kumar and Sen 2021 observed that most of the water harvesting structures like check dams (>35%), percolation tanks (32%) , farm ponds etc were damaged/encroached and calls for immediate actions for rejuvenation in study area and without knowing hydrologic response there is no worthy of water harvesting planning and management studies. Keeping in view, an attempt has taken to study morphometric parameters of the Waghadi watershed using remote sensing and GIS techniques to infer hydrologic behavior which helps the policy makers/decision makers in planning and implementation of water harvesting structures.

MATERIAL AND MEHTODS

Description of study area: Waghadi watershed located in Yavatmal district, Maharashtra prone to drought with total area of 19541.45 ha lies between 20º 19' and 20º 10' N latitude and 78º 4' and 78 º 14' E longitudes (Fig. 1).

The climate is hot and dry with mild cold winters. The area consists primarily of shallow, well-drained, clayey lakhi soils associated with rock outcrops, as well as very shallow, overly drained Moho soils on steeply sloping side slopes. Major crops are cotton, soyabean, pigeon pea, sorghum, wheat, gram etc. The rainfall variation from 2011 to 21018 (Fig. 2) showed there was declining trend of rainfall during the last ten years and gives emphasis on water conservation and surface water harvesting planning in the study area.

Methodology: Manually extracting the drainage network and assign the stream order over a wider area using a published Survey of India (SOI) topographic map and georeferenced satellite data is laborious and time consuming. To overcome this problem, automatic extraction approaches for examining morphometric parameters of a basin were used. The Waghadi watershed was automatically produced from SRTM DEM data (https://earthexplorer.usgs.gov/) with a spatial resolution of 30 m using georeferenced SOI toposheets, and their drainage network was retrieved using a variety of geoprocessing methods. Flowchart of detailed methodology shown in Figure 3.

For hydrological studies, slope, land use/land cover (LULC) pattern, hydrologic soil group as well as morphometric characteristics of study area play significant role. Therefore, slope map was created using spatial analyst tool where as LULC by on screen digitization. However, hydrologic soil group was obtained from NBSS&LUP,

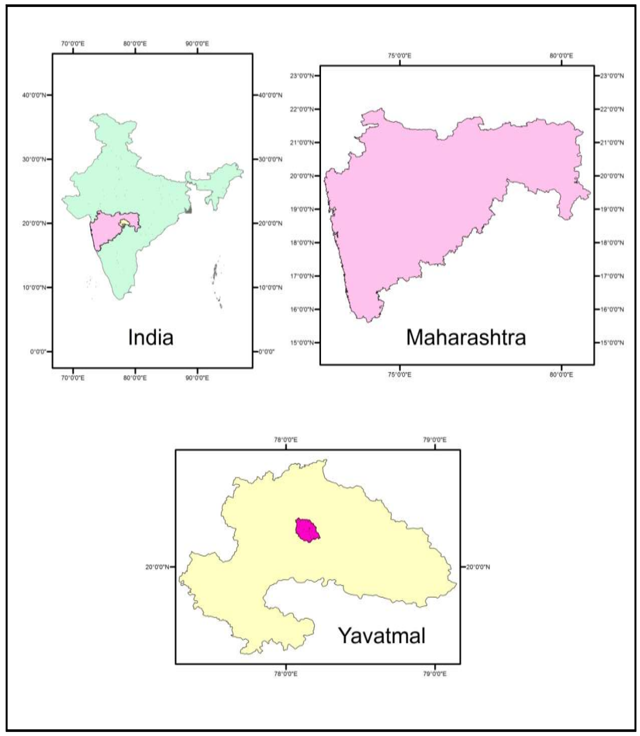

Fig. 1. Location of study area

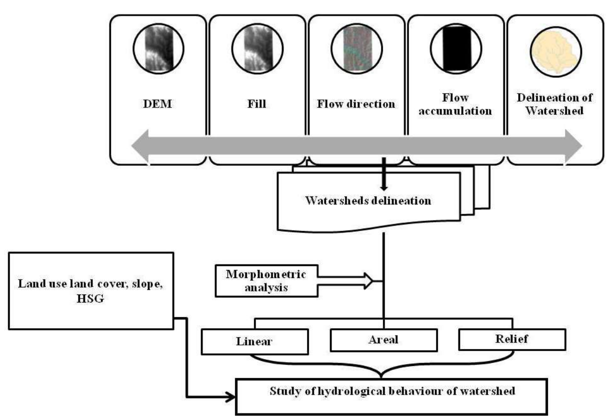

Fig. 3. Detailed flowchart of watershed's hydrological behavior study

Nagpur. The drainage map was prepared using spatial analyst tools (Hydrology) as an Add-on to ArcGIS software. After that, morphometric characteristics like area, perimeter, basin length, total stream length, stream order were calculated using GIS software which were later used to calculate other areal and relief parameters with the help of established mathematical equations (Table 1).

Calculation of Some other Morphometric Parameters of Watershed

Bifurcation ratio (Rb): Bifurcation ratio (Rb) is defined as the ratio of number of streams of any order to the number of streams of the next lower order. This parameter is useful to study the effect of structural control on drainage pattern.

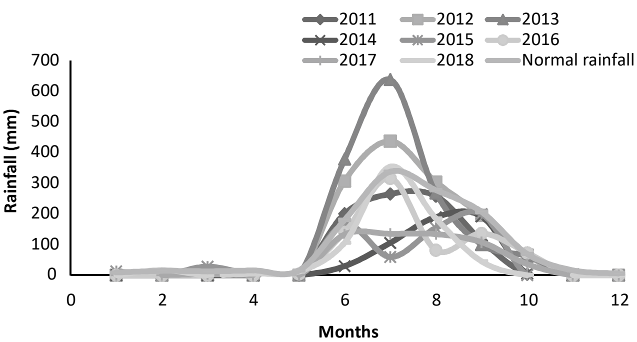

Fig. 2. Rainfall variation trend during last 10 years

Drainage density: Drainage density (DD) is defined as the sum of the channel lengths per unit area. It is generally expressed in terms of miles of channel per square mile or meter per square meter or kilometer per square kilometer.

Form factor: Form factor is defined as ratio of basin area (A) to square of basin length (L_b).

Circulatory ratio: Circulatory ratio is defined as the ratio of basin area (Au) to the area of circle (Ac) having equal perimeter as the perimeter of drainage basin. Generally, its values lie in the range of 0.6 to 0.7.

Elongation ratio: Elongation ratio is defined as the ratio of diameter of a circle having same area as the basin to the maximum basin length (L_b).

Ruggedness number: Ruggedness number (*R*N) is defined as the product of relief (H) and drainage density (DD). Mathematically, they expressed as shown in Table 1).

RESULTS AND DISCUSSION

After delineating the watershed and generating the slope, land use land cover map as well as hydrological soil group map, their hydrological behavior had been studied based on morphometric characteristics viz., linear, areal and relief. Description of thematic layers like slope, Hydrologic soil group and LULC and their detailed morphometric metrics were discussed below**:**

Slope characteristics: The degree of soil erosion is greatly

Table 1. Morphological parameters of watershed

Morphological parameters	Formula	Reference
Basin area ($Km^{2)}$ [A]	-	
Basin perimeter (Km)	-	
Stream length (Km) [L]	-	
Stream order	Hierarchical rank	Strahler (1964)
Basin length (Km) [L_b]	$1.312A^{0.568}$	Nookaratnam et al (2005)
Basin relief (Hb)	$Hb = Z_{max} - Z_{min}$	Strahler (1957)
Drainage Density (DD)	L/A	Horton (1932)
Length of overland flow (Km)	1/(2DD)	Horton (1945)
Form factor	A/L_b^2	Horton (1945)
Circulatory ratio	$4\pi A/P^2$	Miller (1953)
Elongation ratio	$(2/L_b)(A/\pi)^{0.5}$	Schumn (1956)
Compactness coefficient	$0.2821P/A^{0.5}$	Horton (1945)
Stream frequency	Total stream number/ area	Horton (1932)
Bifurcation ratio (Rb)	Rb = Nu/Nu+ 1 Where, Nu = Total no. of stream segments of order 'u' Nu+l= Number of segments of the next higher order	Schumm (1956)
Ruggedness number (*R*N)	Hb*Dd	Schumm (1956)
Relief Ratio (Rh)	Rh = Hb/Lb Where, Rh=Relief Ratio H=Total relief (Relative relief) of the basin in Kilometre Lb= Basin length	Schumm (1956)

influenced by the land slope. Many researchers discovered that the higher the slopes, the greater the erosion, assuming all other circumstances remains constant. Figure 4 showed the slope of the watershed were classified into six categories such as 0-3%, 3-5%, 5-10%, 10-15%, 15-35%, and >35%, based on the feasibility of water harvesting structures (IMSD, 1995). Results revealed that the majority of the watershed has a gentle to moderate slope (3-5%), with exceptionally steep slopes (>35%) located exclusively in the boundary mountainous terrain region.

Hydrological soil characteristics: Hydrological soil classification of Waghadi watershed illustrated that only 2 hydrologic soil group C (58.3%) and D (41.7%), indicates to moderately high to high runoff potential zones, suitable for surface water harvesting (Figure 5).

Land use/land cover characteristics: Land use and land cover is vital for water planning and management in watershed. It is an important component of modelling and comprehending the earth feature system. It also allows for a better understanding of land use issues such as agricultural patterns, fallow lands, forests, pasture areas, wastelands, and surface water bodies, all of which are important for development planning and management. The spatial distribution of distinct classes within the watershed was revealed using a land use/land cover map (Figure 6). It clearly indicated that agricultural land (about 55%) is dominant followed by forest (39%) and least was settlement area (0.73%) (Table 2). Later on, Figure 7 showed a schematic representation of the drainage system, as well as the stream order.

Fig. 5. Hydrologic soil group of study area

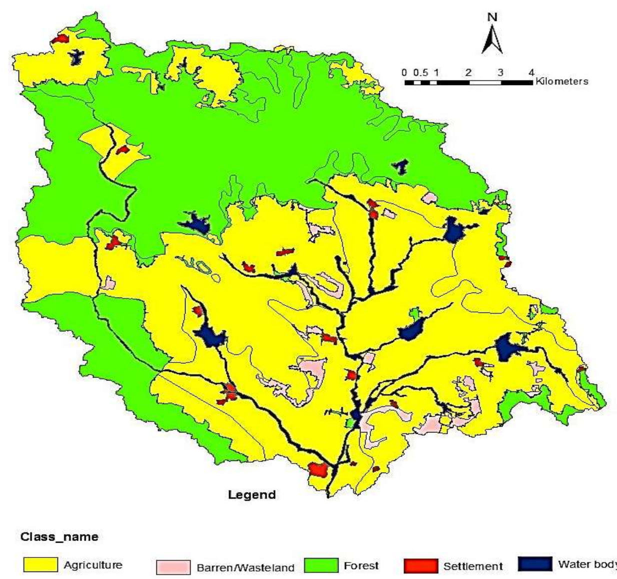

Fig. 6. Land use/land cover (LULC) map

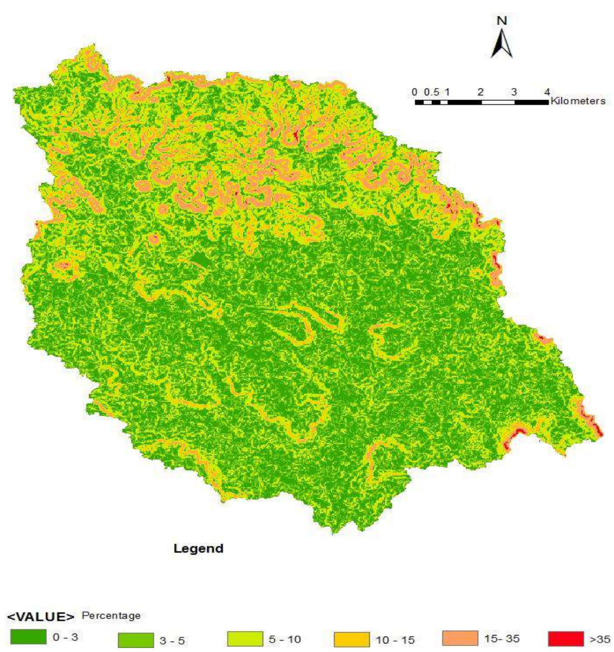

Fig. 4. Slope map of study area

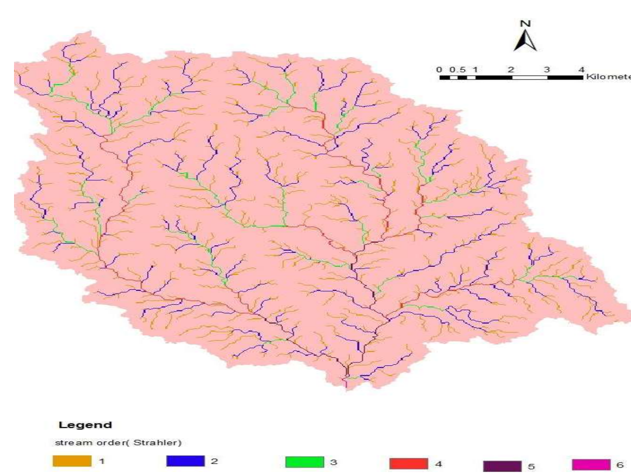

Fig. 7. Drainage network of study area

Analysis of morphometric parameters of watershed: Waghadi watershed is extended to an area of 195.43 km^2 which has a perimeter of 81.27 km. The watershed as a whole is of 6^{th} order, with a total stream length is 470.85 km and a mean stream length ratio is 0.41. In order to examine drainage characteristics in the Waghadi watershed, morphometric analysis was performed. Linear, aerial, and relief features of watershed had been calculated and presented in Table 3.

The Waghadi watershed had a mean bifurcation ratio of 5.92, which indicated a hilly location with moderate to high ground slope, moderate to high run-off, and moderate bed rock permeability. These results demonstrated that the structural changes had significant impact on the drainage pattern of the watershed. A high drainage density indicates a watershed that is well-drained and responds quickly to rainfall events, whereas a low drainage density indicates a watershed that is poorly drained and responds slowly to rainfall events (Melton 1958). The drainage density value was 2.36, which indicated adequate vegetative coverage and moderate permeability (Table 3). The form factor value was 0.28 that indicated to an elongated watershed with a flatter peak flow over a longer period of time. Generally, low value of form factor, the watershed will have a more extended shape. The value of circulatory ratio (0.37), indicated an extended shape with tributaries in their youth period. The length of the overland flow was around 0.85, which indicated the location is relatively high in relief. Reduced rock permeability is generally associated with lower watershed constant of channel maintenance values. The Waghadi watershed's average channel maintenance constant was 0.42, which indicated low to moderate permeability, a high to moderate slope, and a high to moderate surface runoff (Table 3).

Basin morphological characteristics and the basin relief ratio (Schumn 1956, Chopra et al 2005, Rudraiah et al 2008) showed the overall steepness of a drainage basin and the intensity of erosion processes operating on the slope of the basin (Schumn 1956, Chopra et al 2005, Rudraiah et al 2008, Hadley and Schumm 1961). The basin relief ratio (0.01) showed a high to moderate slope in the region, which is characterized by plateau with undulating landforms. The Ruggedness number (Rn) was also taken into consideration during the examination. It described the smoothness and roughness of the basin, as well as its vulnerability to soil erosion at the watershed level (Selvan et al 2011, Gutema et al 2017). Ruggedness values range from 0 to 1. The value close to 0 indicates a comparatively smoother environment, while value nearer to 1 indicates more difficult terrain features. The ruggedness number of watershed (0.44), showed moderated rugged topography.

Table 2. Distribution of different LULC classes

LULC classes	Area (ha)	% Area distribution
Agriculture land	10683.97	54.67
Forest	7626.21	39.03
Barren/Wasteland	411.70	2.11
Settlement	143.45	0.73
Water body	676.11	3.46

Table 3. Morphometric parameters of watersheds

Parameters		Values
Area (km^2)	Linear	195.43
Perimeter (km)		81.27
Total no. of stream order		6
Basin length (km)		26.25
Total stream length (km)		470.85
Mean stream length ratio		0.41
Mean bifurcation ratio		5.92
Drainage density (km/km^2)	Areal	2.36
Form factor		0.28
Circulatory ratio		0.37
Elongation ratio		0.6
Length of overland flow (km)		0.85
Constant of channel maintenance		0.42
Basin relief (m)	Relief	0.186
Relief ratio		0.01
Ruggedness number		0.44

CONCLUSION

Drought-like conditions persist every year in the Waghadi watershed of Maharashtra due to low average rainfall and call for integrated watershed management for which thorough understanding of a watershed's hydrological behavior play an important role. However, Government of India gives more emphasis on in-situ water harvesting under jal sakti abhiyaan and decision about site suitability for water harvesting structures without knowing morphological parameters is no worthy. Keeping these facts, remote sensing and GIS based approach to study hydrological response of Waghadi watershed through morphometric analysis has been carried out and overall concluded that watershed is of 6^{th} order, elongated in shape with dendritic to sub dendritic pattern. Agricultural land (55%) is dominated followed by forest (39%) and it mainly consists of Hydrologic soil group C (58.3%) and D (38.8%) showed moderately high to high runoff potential zones, most favorable for water harvesting structures. However, majority area comes under gentle to moderate slope (3-5%) and it provide suitable environment for construction of water harvesting structures whereas upper and boundary regions mainly hilly areas consists of moderate steep to very steep (>35%),unfavorable for water harvesting structures but may be favorable for ground water recharge structures. Overall, it has been recommended that there is huge scope of harvesting the surface runoff and construction of water harvesting structures, has been suggested as a way to improve agriculture through irrigation in these places from hydrological point of view, rather than relying on rain fed agriculture.

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Flood-Prone Area Mapping of Manu-Deo River Basin, Tripura using GIS and RS

Suman Debnath, Laxmi Narayan Sethi, Avinash Kumar, Nirmalya Kumar Nath[1] and Vinay Kumar Gautam[1]*

Department of Agricultural Engineering, Triguna Sen School of Technology
Assam University, Silchar-788 011, India
[1]Department of Soil and Water Engineering, CTAE, MPUAT, Udaipur-313 001, India
[*]E-mail: drvgautam95@gmail.com

Abstract: The present study has been undertaken for flood mapping integrating flood conditioning parameters through Analytical Hierarchal Process (AHP) utilizing Digital Elevation Models (DEMs) obtained by (Shuttle Radar Topography Mission) SRTM in a Geographic Information System (GIS) and Remote Sensing (RS) environment. The flood conditioning parameters such as elevation, slope, drainage density, flow accumulation, land-use land cover, annual rainfall, and stream order are selected for creating the thematic map using Digital Elevation Models (DEMs) obtained by (Shuttle Radar Topography Mission) SRTM and predicted area wise severity of flood hazard. The study revealed that around 13.43% of the study area and the cities like Kailashahar, Kumarghat, Pencharthal, and Kanchanpur having very little elevation, high drainage density and huge built-up were profoundly inclined to floods. However, the hilly regions or top-down portions (i.e., sources of the river) of the study area were spotted to be less prone to floods. This study will help to policy makers to recognize the hotspots of flood affected area to avoid any undesirable situation during monsoon season.

Keywords: AHP, Flood, DEM, SRTM, RS and GIS

Flood, landslides, earthquakes, tsunamis, drought, cyclones, volcanic eruptions, etc., are the different natural calamities that bring colossal disturbance to the ecosystem by demolishing various resources that disrupt a community's activities. Among all these natural calamities, flood is considered one of the most commonly occurring phenomena that strikes everywhere around the world (Das 2019, Kayastha et al 2013, Marchand et al 2009, Shen and Hwang 2019). Due to floods, a remarkable increase in disruption of economic activities, livelihood, and loss of life has been found over the past decades around the world (Gaume et al 2009).

India, due to its unique geo-climatic, and socio-economics is vulnerable in varying degrees to those natural calamities mentioned above and that they vary from region to region. In line with National Disaster Management Authority (NDMA) report of 2018, 58.6% of the Indian mainland is exposed to earthquakes of moderate to very high intensity; 12% of the land is susceptible to flood, and river erosion and a complete of 5,161 Urban Local Bodies (ULBs) are at the risk of urban flooding. The North-Eastern region of India is roofed by the mighty Brahmaputra-Barak River system and its tributaries. The southwest monsoon brings incessant rainfalls in this region which causes frequent floods (Trivedi et al 2021, Nath et al 2022). Avand et al (2020) identified the effects of changing climates and land uses over 20-18 years on flood probability using machine learning models by land change modeler (LCM) and Lars-WG software. Conicelli et al (2021) applying GIS and classic recharge methods determined groundwater availability and aquifer recharge in highly urbanized watersheds. Das (2020) generated a flood susceptibility map of the Western Ghat coastal belt combining multi-source geospatial data and analytical hierarchy process. MCDA has been broadly acknowledged as a significant procedure for dissecting complex choice issues which regularly include beyond reconciliation incommensurable rules (Malczewski 2006, Hwang and Lin 2012). The countless approach was created to generate flood-prone area maps such as adaptive neuro-fuzzy (Mahmound and Gan 2018), frequency ratio (de Santana et al 2021), analytical hierarchy process (Das 2018), statistical methods (Wang et al 2021), random forest (He et al 2022). The Analytical Hierarchy Process being one of the MCDA techniques is a subjective strategy where the system and its application depend on the specialist's information in assigning weights (Saaty 1980).

Flood mapping helps in deciding the protective measures that are to be taken to mitigate or to overcome the natural flooding phenomenon by promoting risk management, land use land cover management, flood forecasting (Kazakis et al 2015). Flooding is a multidimensional complex phenomenon that causes flood mapping through ground survey and ariel observation to take time and also needs an experienced person. In recent years GIS/RS framework has significant attention from many researchers to investigate the expanse of flooded areas or computing natural calamities. The Geographic information system (GIS), is a framework that integrates, manages, and analyses the various types of input data, and systematizes the layer of information into visualization using maps and 3D scenes (Gautam et al 2021). This distinctive natural proficiency of GIS helps the user to frame smarter decisions by looking after the patterns, relationships, and solutions that are envisaged in the GIS environment by understanding the data in the form of a thematic map (Gautam et al 2023). Remotely-sensed data provide information by interpreting various features present on our planet and presenting it in the form of several digital images (Abdelkareem and El-baz 2017, Abdelkareem et al 2018). The combination of both GIS and RS techniques is extremely productive to generate flood-prone area mapping which comes up with substantial accuracy (Bates 2012, Nikoo et al 2016, Pradhan 2009, Rahmati et al 2016)

Almost every year, the cities nearby the Manu and Deo River get affected by floods which, causes hazards to human settlements as well as the economy. Understanding the flood dynamics by flood mapping is needed to predict floods and tackle future damages caused by floods. There are various ways to collect data, required for the study area but remote sensing high-resolution precise data are more effective than field survey. Currently, the GIS tool is commonly used for preparing and predicting flood hazard maps but applying (Analytical Hierarchal Process) AHP as a decision-making technique is still lacking in such study. Therefore, an attempt has been made to prepare a flood hazard map by applying AHP for the Manu-Deo River basin, Tripura by integrating flood conditioning parameters in a GIS environment. The principal objective of this study is to get familiar with and prepare flood hazard maps of the areas which are most prone to floods under the Manu-Deo River basin using GIS and RS which will help in taking protective measures to mitigate the destruction caused by the floods.

MATERIAL AND METHODS

Study area: The Manu-Deo River basin comes under three districts of Tripura i.e., Unakoti, North Tripura, and Dhalai, which is located between 23°15' N to 24°27' N latitude and 91°50' E to 92°18' E longitude (Fig. 1). The state of Tripura is blessed with well surface water resources. As per the report, 793 million cubic meters of water flow through ten major rivers annually. The Manu River originated from the Sakhan range which is northerly flowing through Kailashahar to

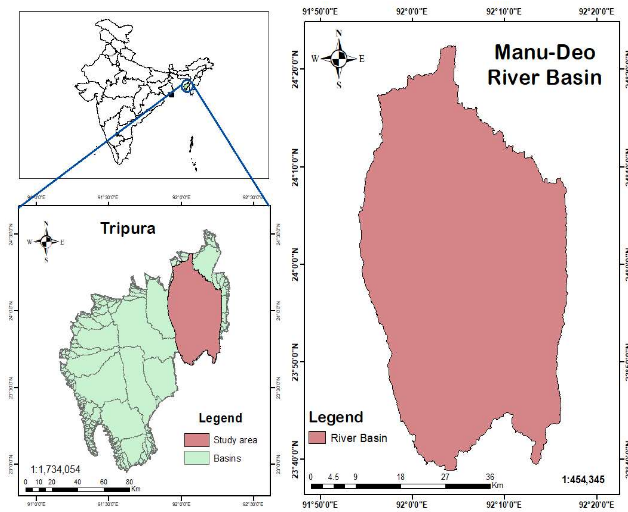


Fig. 1. Location of the Manu-Deo River basin

Bangladesh. An approximate length of 167 km makes it the. The longest river in Tripura. Whereas, 98 km long the Deo River move towards northward direction meets the Manu River via Kanchanpur valley and its origin is Jampui Hill.

Total area of the Tripura state is around 10,500 sq. km, have ten major rivers and other streams. Among them, the Manu-Deo River is the second largest river basin of Tripura covering 1,979 km^2 (18.36%) of the total basin area (The State of Environment in Tripura, 1989, CSME). The annual rainfall of the state varies from 1922 mm to 2855 mm. Humidity is usually high throughout the year; in the rainy season, it's over 85 percent while the average, maximum and minimum temperatures is 35.60°C and 4°C respectively. Rainfall is the major source of the generation of surface water in Tripura. It is noticed that the Manu-Deo River generates an annual flow of 170 million cubic meters of water which is 21.44% of the flow to total flow (The State of Environment in Tripura, 1989, CSME). Southwest monsoon contributes 60% of annual rainfall in this state, June being the highest rainfall receiving month followed by July. It was reported that 2542.5 mm as the highest mean annual rainfall in North Tripura district (98-104 days) and maximum (62-65 days) frequency of rainy days observed in the northern part of Dhalai, Unakoti, and North Tripura (IMD report 2020).

Sources of data: For flood-prone area mapping the Shuttle Radar Topographic Mission (SRTM), Digital Elevation Model (DEM) data was used (Hong et al 2018b). The SRTM, DEM data (Source: https://earthexplorer.usgs.gov/) of 30m spatial resolution was obtained from USGS Earth Explorer which helped in delineating the required river basin. To understand the current landscape of the study area Landsat 8 data of 1:50,000 scale for Land use land cover (LULC) map was acquired from USGS Earth Explorer. Pixel data of interannual rainfall from 1998 to 2019 (Source: https://power.larc.nasa.gov/data-access-viewer/).

Analytic Hierarchy Process (AHP)

Implementation of AHP: The AHP involves the pair-wise comparison of the criteria assigned by the decision-makers and generates the weight of each criterion. The higher the score better the performance. Implementation of the AHP involves three successive steps: i) computing the vector if criteria weight, ii) computing the matric option scores, and iii) ranking the options.

Checking the consistency: For checking the consistency, the consistency index (CI) needs to find first. It can be computed as given below.

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

Where, λ_{max} is eigenvalue; n is the number of criteria or factors. The consistency ratio gives the required level of consistency, that is obtained using CI and RI.

$$CR = \frac{CI}{RI}$$

Where, CR is the consistency ratio; CI is the consistency index, and RI is the random index. The acceptable consistent ratio (CR) value should be below 0.1 (i.e., R < 0.1) otherwise it will call as inconsistent. The RI value that is to be used is according to Table 1.

To prepare thematic layers, different geo-spatial data have been collected from their respective sources for the study area using ArcGIS 10.3. The final flood-prone area map was prepared by integrating all the factors in the (Geographic Information System) GIS environment with an allocated weighted value of the respective parameters. Whereas, the hierarchical classification based on the flood vulnerability was done by the Analytical Hierarchal Process (AHP) Technique shown in Figure 2.

RESULTS AND DISCUSSION

Elevation: The elevation (i.e., distance above the sea level) of the study area varies from 18m to 940m which were classified into six classes Figure (3a). Elevation with a higher value as steeper topography, resulting in less vulnerability to floods.

Slope: As the slope of an area goes on decreasing the infiltration rate starts increasing as a result surface runoff decrease and it creates a flooding situation where the water starts overflowing and stops the water from reaching the river channel. Hence, the higher the topographic gradient lesser the probability of occurrence of flood. The five classes of slopes that have been categorized depending on their susceptibility to inundating: very low, low, medium, high, very high. Breaking values were taken based on experts' knowledge, local information (Fig. 3b).

Drainage density: The areas with extremely high river discharge led to an increase in the occurrence of floods, thus it's a crucial factor in flood mapping (Mahmoud and Gan 2018, Ogden et al 2011). The drainage density was between 0 to 2.5 km/km^2, which has been classified into five classes (Fig. 3c).

Flow accumulation: Flow accumulation indicates the accumulated weight of the watershed flowing through the outlet toward the downslope. It is a very important factor that has a great influence on flood mapping. Increasing the value of flow accumulation leads to an increase in flood-prone areas (Lehner et al 2006). This flow accumulation map is generated by flood accumulation tools in ArcGIS and categorized into five classes based on natural breaks. It is useful in the generation of stream networks (Fig. 3d).

Land use land cover: Land use land cover adversely affect the flood propagation and varies from less impervious land to more impervious land, on the other way the forest has a big capacity to intercept the rainfall as compared to vegetation

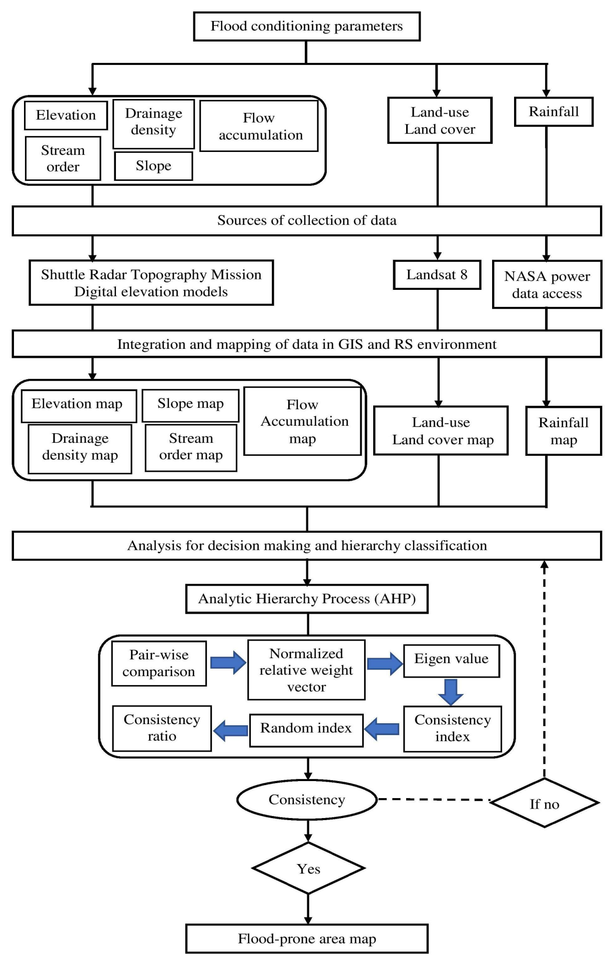


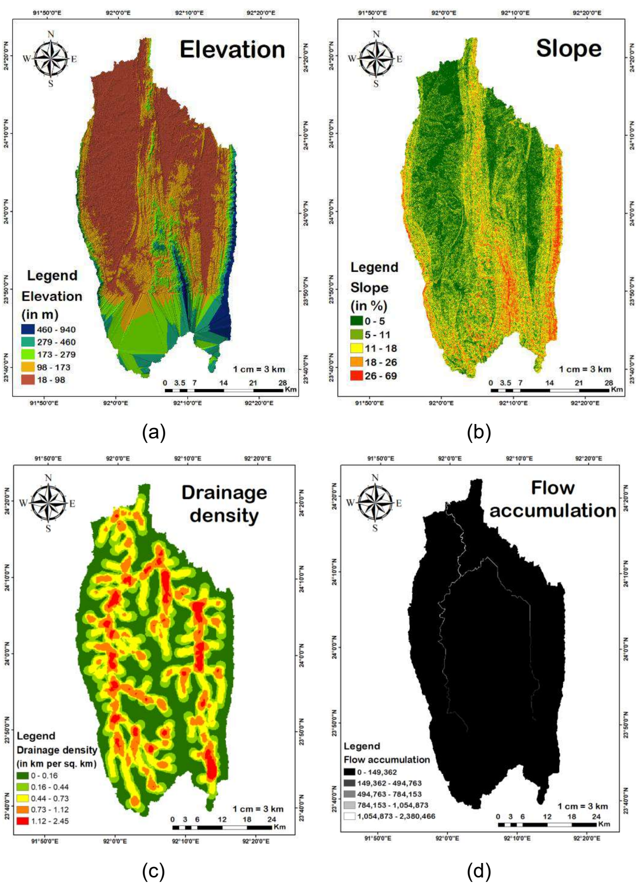
Fig. 2. Flow chart of flood-prone area mapping for the Manu-Deo River basin

land or scrubland. Land use pattern has a strong tendency to control the flooding consistency (Benito et al 2010, Garcia-Ruiz et al 2008). Transformation in land use can lead to an increase in the occurrence of floods in an area (Beckers et al 2013). The prepared LULC map in this study is of eight land use classes i.e., Deciduous Forest, cropland, built-up land, mixed forest, shrubland, waterbodies, plantation, evergreen forest (Fig. 4a).

Rainfall: It is evident that rainfall has a great impact on river flooding as many have established the relationship between flood occurrence and rainfall (Goel et al 2000, Hong et al 2018a, 2018b, Zhao et al 2018). The map prepared here was based on of last 20 years' annual rainfall data which were categorized into five classes based on the amount of rainfall received by different stations within the study area and maximum or minimum rainfall found to be 1869 or 1790 mm/year respectively (Fig. 4b).

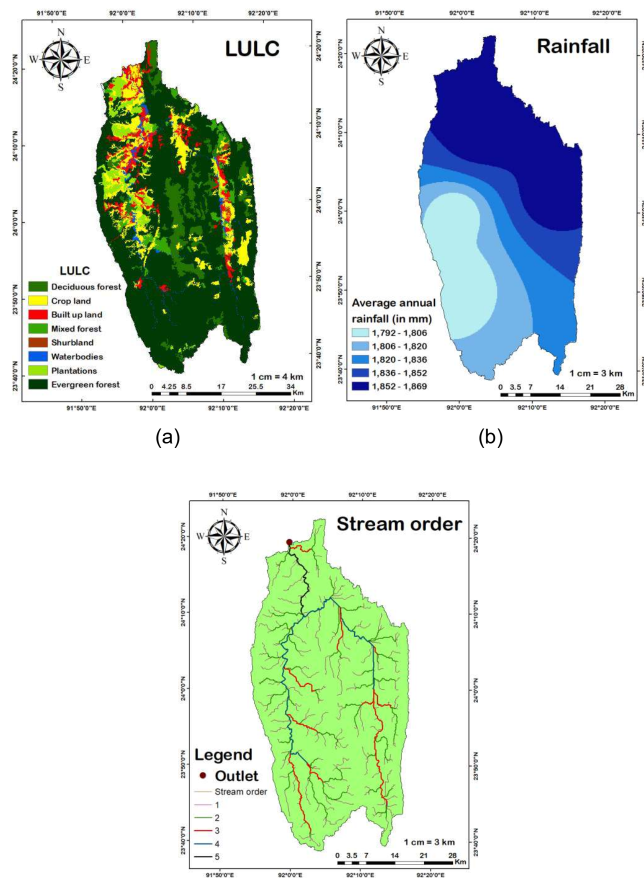
Stream order: Water starts overflowing when the amount of water drained through the steam gets beyond its capacity. Usually, a flood occurs when a greater number of streams collect water from different areas and passes through the mainstream i.e., higher the level of branching in a river system leads to the increase in the occurrence of floods, and areas nearby the river mouth are more prone to the flood as compared to areas top-down surrounding areas. The stream network system of the study area was divided into five orders Figure 4(c).

Consistency checking: The numerical values of the pairwise comparison matrix shown in Table 2 give the qualitative evaluations of the relative importance between



(a) (b) (c) (d)

Fig. 3. Thematic maps for flood conditioning parameters, (a) Elevation, (b) Slope, (c) Drainage density (d) Flow accumulation of the study area



(a) (b) (c)

Fig. 4. Thematic maps for flood conditioning parameters (a) LULC, (b) Rainfall, (c) Stream order of the study area

Table 1. Values of the Random Index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.21	1.24	1.32	1.41	1.45	1.49

Source: Saaty 1980

the two parameters. The relation between numerical values and high respective importance was: 1, 3, 5, 7, and 9 represents the equally slightly more, more, strongly, and absolutely more important respectively whereas less significant variable was allotted by reciprocal of that number (Saaty 2004, Kandilioti and Makropoulos 2012), The normalized matrix values whose average (along the rows) gives that criteria weight value of each parameter (Table 3). The average of the ratio of weighted sum value to the criteria weight calculated. It represents the value of the eigenvector (Table 4).

λ_{max}= (7.79 + 7.97 + 7.57 + 7.40 + 7.80 + 6.75 + 8.00)/7 = 7.60

Applying the following equation, consistency index was calculated by computing the average eigenvalue and the number of criteria that have been used in the study.

$$CI = \frac{7.60 - 7}{7 - 1} = 0.1$$

Using the following equation, consistency ratio was simplified by considering 1.32 as a random index value for seven criteria.

$$CR = \frac{0.10}{1.32} = 0.08$$

The obtained value of CR as 0.08<0.1 signified that the weighted value allocated to the respective parameters like elevation, slope, drainage density, flow accumulation, land-use land cover, rainfall, and stream order as 0.37, 0.26, 0.15, 0.10, 0.05, 0.04 and 0.02 respectively were consistent.

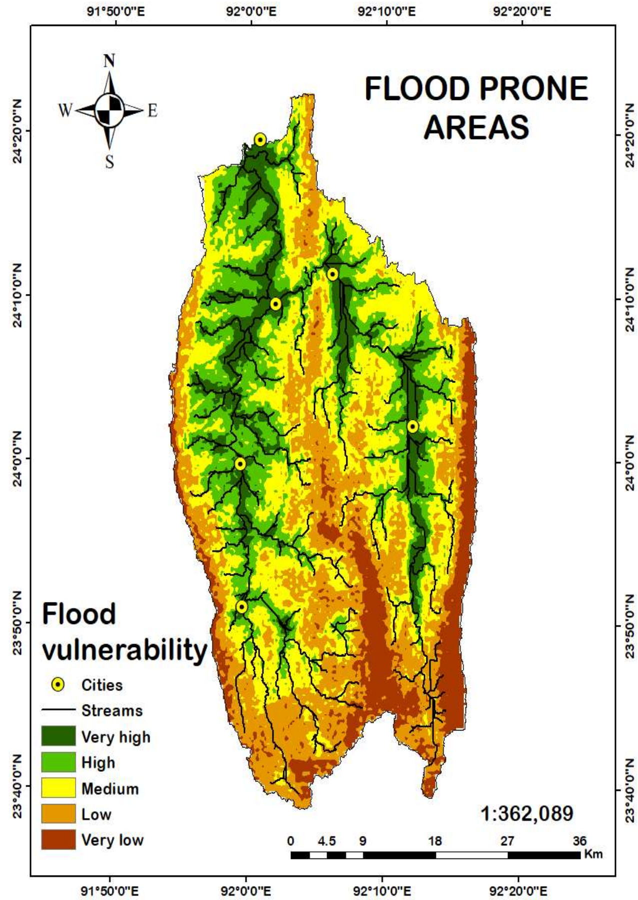


Fig. 5. Flood-prone area mapping of the Manu-Deo River basin

Table 2. Pairwise of comparison matrix of all the parameters

Parameters	Elevation	Slope	Drainage density	Flow accumulation	LULC	Rainfall	Stream order
Elevation	1	2	4	5	7	8	9
Slope	1/2	1	3	4	6	7	8
Drainage density	1/4	1/3	1	2	4	6	7
Flow accumulation	1/5	1/4	1/2	1	3	4	5
LULC	1/7	1/6	1/4	1/3	1	2	4
Rainfall	1/8	1/7	1/6	1/4	1/2	1	3
Stream order	1/9	1/8	1/7	1/5	1/4	1/3	1

Table 3. Criteria weight of all the parameters for AHP technique

Parameters	Elevation	Slope	Drainage density	Flow accumulation	LULC	Rainfall	Stream order	Criteria weight
Elevation	0.43	0.50	0.44	0.39	0.32	0.28	0.24	0.37
Slope	0.21	0.25	0.33	0.31	0.28	0.25	0.22	0.26
Drainage density	0.11	0.08	0.11	0.16	0.18	0.21	0.19	0.15
Flow accumulation	0.09	0.06	0.06	0.08	0.14	0.14	0.14	0.10
LULC	0.06	0.04	0.03	0.03	0.05	0.07	0.11	0.05
Rainfall	0.05	0.04	0.02	0.02	0.02	0.04	0.08	0.04
Stream order	0.05	0.03	0.02	0.02	0.01	0.01	0.03	0.02

Table 4. Determination of eigen value

Parameters	Elevation	Slope	Drainage density	Flow accumulation	LULC	Rainfall	Stream order	Weighted sum	Criteria weight	Weighted sum/Criteria weight
Elevation	0.37	0.53	0.60	0.50	0.38	0.30	0.21	2.88	0.37	7.79
Slope	0.19	0.26	0.45	0.40	0.33	0.27	0.18	2.07	0.26	7.97
Drainage density	0.09	0.09	0.15	0.20	0.22	0.23	0.16	1.14	0.15	7.57
Flow accumulation	0.07	0.07	0.07	0.10	0.16	0.15	0.11	0.74	0.10	7.40
LULC	0.05	0.04	0.04	0.03	0.05	0.08	0.09	0.39	0.05	7.80
Rainfall	0.05	0.04	0.02	0.02	0.03	0.04	0.07	0.27	0.04	6.75
Stream order	0.04	0.03	0.02	0.02	0.01	0.01	0.02	0.16	0.02	8.00

All the seven multi-sources environmental criteria that were considered in this study were merged to generate a flood-prone area map. The preferences given to the flood condition parameters were based on the weighted value generated by the AHP technique. The resulting map prepared by overlaying was classified into five classes dependent on the natural breaking method. They are as follows: very high, high, medium, low, and very low. After calculating the area under flood-prone it was found that 282.96 km^2 (13.43%), 450.40 km^2 (21.38%), 596.70 km^2 (28.32%), 531.92 km^2 (25.25%), and 244.77 km^2 (11.62%) of the total area were corresponded to very high, high, medium, low, and very low vulnerable to floods respectively (Fig. 5). The city of Kailashahar, Kumarghat, Manu, Pecharthal, Kanchanpur across the basin come under very high flood-prone zone including some portions of the cropland or flat land areas nearby the main streams. On the other hand, hilly areas or top-down portions (i.e., sources of the river) were spotted to be less prone to floods. The areas with very little elevation, zero slopes, high drainage density, excessive-high flow accumulation, and huge built-up areas are very highly prone to floods.

CONCLUSION

The flood-prone area map of the Manu-Deo River basin was prepared using GIS and RS applying AHP techniques as an effective tool for complex decision making. The areas with lower elevation, slope, and high flow accumulation are very highly prone to floods. Additionally, the intensity of floods was observed to be very high in the areas with the highest number of recorded historical flooding events within the study area. There is the lowest percentage of areas where chances of affected areas with floods are very less. The AHP model used was accurate and reliable when used together with GIS and RS. Hence, the map of flood-prone areas presented in this paper can be used in preparing flood maps of other areas and also may help the organizational bodies, engineers, policymakers, builders, service providers in tackling floods in the Manu-Deo River basin.

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Attitude of Local Communities Towards Human-Wildlife Interactions and Wildlife Conservation in the Peechi-Vazhani Wildlife Sanctuary, Thrissur, Kerala

P.V. Nikhil, A. Muhammed Iqbal, K.S. Aneesh and S. Gopakumar

Department of Forest Resource Management
College of Forestry, Kerala Agricultural University, Thrissur-680 656, India
E-mail: nikhil-2018-47-028@student.kau.in

***Abstract*:** A questionnaire survey was carried out among the local people and tribal communities in and around the Peechi-Vazhani Wildlife Sanctuary in the Thrissur District of Kerala to understand the attitude towards human-wildlife interactions and wildlife conservation. A total of 60 respondents were interviewed, and the responses were recorded. Crop raiding was the most important result of the conflict, followed by cattle depredation. Conflicts in the study region were driven mainly by increased food availability in the forest fringes. The most conflicting animal was the wild boar (*Sus scrofa*), followed by the giant squirrel (*Ratufa indica*). Proper awareness programs, interactions among stakeholders, and participatory maintenance of mitigation methods are essential for the coexistence on the fringes of this protected area.

***Keywords*:** Human-wildlife Interactions, Attitude, Crop raid, Livestock depredation, Mitigation measures

The phrase "Human-Wildlife Conflict"(HWC) has gradually evolved through time into "Human-Wildlife Interactions" by gaining several dimensions. One of the most challenging issues conservationists face today is handling human-animal interactions. Local communities suffer enormous economic losses due to crop destruction, livestock loss, and human-animal confrontations that result in either life loss or injury. Retaliation against animals occurs from this, which causes animal lynching or herbivore poisoning. Resolving the problem of human-animal interactions in India is difficult because many human settlements are near protected areas which make conservation efforts difficult (Karanth et al 2008). There are many causes for HWC. Due to urbanization, intensified agriculture, and increased human population, wild animals are experiencing habitat loss and degradation (Nyhus 2016). Despite decades of research and significant financial effort, it is still unknown what ecological and social factors contribute to human-wildlife interactions (Dickman 2010). Protecting biodiversity is not just about advocating for cohabitation as we understand it with wildlife. Prior studies on quantifying the damage arising from conflicts are popular. However, the public's attitude towards conflict and wildlife, an essential factor in mitigation programs, still needs to be examined (Rohini et al 2018, Govind and Jayson 2018). This paper outlines the attitude of local communities living in and around the Peechi-Vazhani Wildlife Sanctuary towards the effects of human-wildlife interaction.

MATERIAL AND METHODS

Peechi-Vazhani Wildlife Sanctuary, the research area, is located between latitudes 10°28° and 10°38°N and longitudes 76°18° and 76°28°E. This sanctuary is bordered to the north and west by the Thrissur Forest Division, to the east by the Nenmara Forest Division, and to the south by the Chalakkudy Forest Division and the Chimmony Wildlife Sanctuary. The sanctuary covers roughly 125 Sq.km of land. It is the watershed area for the Peechi and Vazhani reservoirs. The region comprises Tropical evergreen forests, Tropical semi-evergreen forests, and Moist deciduous forests which support diverse fauna and flora. Human settlements in Olakara, Maniyankinar and Jandamukk regions, falling under the Peechi forest range, were chosen for the study (Fig. 1).

A questionnaire survey, with open and closed-end questions, was used from May to July 2022 to examine the attitudes toward human-wildlife interactions. The study was conducted in three selected human settlements in the sanctuary, Olakara, Maniyankinar, and Jandamukk. Interviews were conducted among 60 individuals residing in tribal settlements and forest fringes. In-depth data on the scope of human-wildlife interactions, the most significant type of conflict, its pattern, and attitudes toward forest and conservation efforts were collected. The data was compiled, and the responses to different questions were evaluated using percentage analysis.

RESULTS AND DISCUSSION

Extent of conflict: The major consequence faced by the residents was crop raiding (93%), followed by livestock loss, habitat destruction and human property damage (21%). Injury and loss of life of humans are faced by 18% of the people. All the residents faced difficulties in cultivation due to wild animals. The top five conflicting animals were wild boar (82%) followed by Giant squirrel, Elephant, Monkey, and Peafowl (35%). About 70% of the people had an opinion that conflict occurred during night hours (18:00 to 6:00), while 14% during day time (6:00 to 18;00) and 15 % during both. While rating the fear of conflict (from 0 to 5) most people fell under the rating of 2. 88 % of the individuals haven't faced attacks from wild animals.

Most individuals (96%) believed that the interactions have increased compared to the last decade. However, 4% respond that no change has happened in the intensity of the interactions. 72 % of respondents believe that increased availability of food is the cause of increased conflicts, followed by habitat degradation (15 %) and fragmentation (13%) (Fig. 4). Furthermore, 58 % of the people believed that most conflict incidents occur during the rainy season, while 25% throughout the year and 17% in the non-rainy season (Fig. 5).

The cultivation status of various crops was examined without regard for the area of land owned by individuals. Coconut was the most widely cultivated among all the cash crops followed by rubber and ginger (Fig. 6).

Attitude toward the conservation of wildlife: Compensation for wildlife damage is a prominent tool for resolving human-wildlife conflicts (Ravenelle and Nyhus 2017). However, 86 % of the individuals do not receive proper compensation for the losses due to conflict. Only 14% of the respondents have received the compensation in which 65.5% of them are satisfied with the amount. 61% were not ready to migrate from their place, while 39% of the people were willing to relocate if the government gave proper alternatives. When the effectiveness of the mitigation strategies was examined, 69% of the respondents claimed they were effective in controlling the conflicts, while others stated they were ineffective. When the perception on the forest department and officials was analyzed 56% of the individuals responded that they were helping, 32% said it was not helping, and 12% responded as strictly avoiding.

Various studies on human-wildlife interactions in different regions made similar conclusions. However, significant variations can be seen in the responses to the conflict. The attitude to interactions frequently seems out of proportion, and even minor wildlife harm might result in violent reactions (Dickman 2010). Most studies report that crop raiding is an assured outcome of the conflict (Easa and Sankar 2001, Nair and Jayson 2016, Rohini et al 2016). The increased

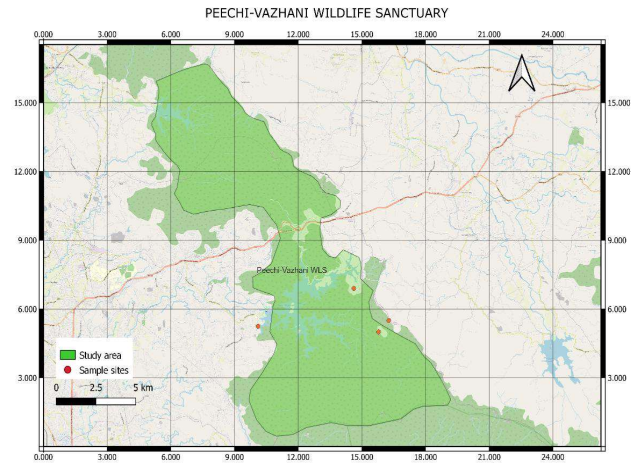

Fig. 1. Peechi-Vazhani wildlife sanctuary

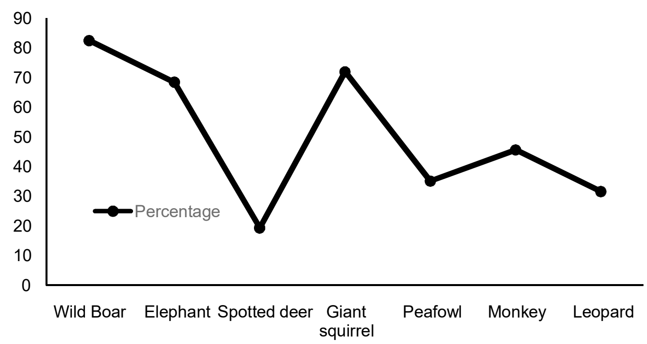

Fig. 2. Status of conflicting animals

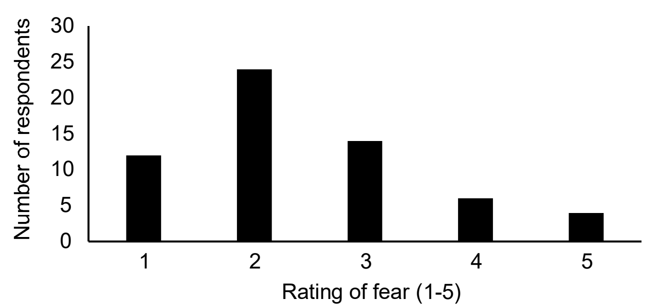

Fig. 3. Fear of wild animals

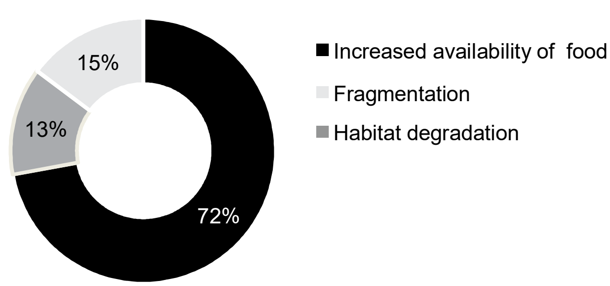

Fig. 4. Causes for the conflict in the study area

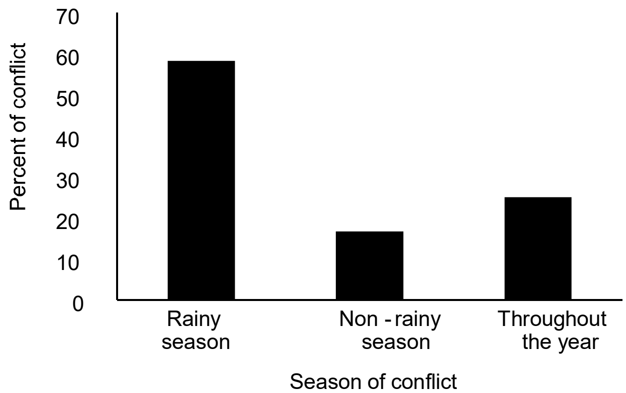

Fig. 5. Season of conflict in the study area

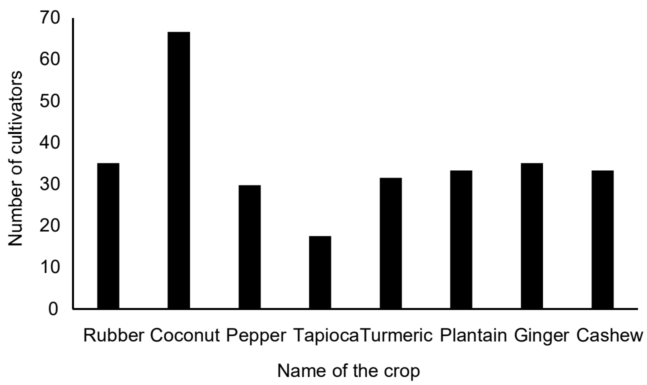

Fig. 6. Cultivation status of different crops

availability of food was identified as the key driver of the conflicts. The diverse cropping systems in the forest fringes attract wild animals. Previous studies also provide similar observations(Rohini et al 2018, Karanth et al 2019). Wild boar (*Sus scrofa*), followed by Malabar giant squirrel (*Ratufa indica*) and Elephant (*Elephas maximus*) were the top most conflicting animals. Similar studies also identify the conflicting status of different animals (Easa and Sankar 2001, Karanth et al 2013, Govind and Jayson 2018). The 81% responded that wildlife should be conserved, while 19 % were not interested in wildlife conservation. Comparable results were obtained by Rohini et al (2016) when the attitude towards elephants in the southern western ghats of Kerala was analyzed. Perceptions of people about the lack of proper compensation and long-term procedures for the same from the forest department were close to previous studies (Gubbi 2012, Karanth et al 2013). Intensive crop damage and the increasing frequency of animal attacks have created distressed conditions among the residents. This situation has also affected people's tolerance towards wildlife. Collaborative efforts with a long-term vision must be designed to mitigate the impacts of human-wildlife interactions in this region.

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Human Wildlife Competition due to Population Growth in Ecosystem: Principle of Coexistence

Sanjit Kumar Saha and Rinki Mukherjee Saha[1]

Directorate of Forests, Government of West Bengal, Kolkata-700 106, India
[1]Freelance Science and Conservation Communicator, Kolkata-700106, India
E-mail: sanjitwbfs@gmail.com

***Abstract*:** The estimated population of one horned Rhinoceros (*Rhinoceros unicornis*) of Jaldapara National Park has increased from the year 2019 to 2022, with growth of 23.20%. Excluding National Park area, human Population density of Madarihat-Birpara Block also has been increased from the census year 2001 to 2011 @46.83 people per unit area. Increase of Rhino population density is very meagre during the last 3 years from 2019 to 2022 in the Jaldapara National Park. Here Growth of human population though less significant, but density wise significance is much more than the Rhino population in the ecosystem of the same landscape. Apart from Rhinoceros, increasing population of other herbivores and carnivores are engaged in intra and interspecific competition for space, food and shelter in the fixed area of the National Park of that landscape. Population of wild animal beyond the carrying capacity leads to stray in the adjacent human habitation and ultimately leads to conflict and competition between human and wild animal. It is resulting into injury, death of either wild animal or human. In this field-based work during 2019 to 2022, apart from sensitization, awareness creation forest department adopted lots of innovative methods along with the community participation and assured compassionate coexistence between human and wild animal in the same landscape of shared ecosystem.

***Keywords*:** Population growth, Human wildlife competition, Population density, Landscape, Deaths, Compassionate coexistence

The interaction between humans and elephants is often referred to as conflict, however, it is also seen as competition (Davidar 2018). Human-elephant competition (HEC) (Davidar 2018) is a negative interaction between the two species, resulting in crop loss, property damage, and can lead to the loss of life of both humans and elephants (Saha 2020). Competition may be direct and indirect (Saha 2020). The forest department promotes coexistence through different means with the help of local joint forest protection committees (JFPCs) (Saha 2020). Conflicts between wildlife and humans cost many lives, both human and wildlife, threaten the livelihoods of millions worldwide and jeopardize long-term conservation goals such as securing protected areas and building constituencies in support of wildlife conservation (Sukumar 1994, Treves and Naughton-Treves 2005). Most landscapes are now dominated by humans (Sillero-Zuberi et al 2007). In indirect competition people live in fear of elephants, which restricts free movement and day to day activities of people in forest fringe areas. Conflict occurs between competing interests for environmental resources; and solutions need compromise and strategies that do not necessarily involve sealing people off from nature but, on the contrary involve a respectful engagement with wildlife (Macdonald 2001). In Gir National Park, Gujarat in 2013 interaction with the local farmers of the fringe areas it was observed that local farmers were very happy co-existing with lions in that landscape, although lions hunt the livestock of the local farmers (Saha 2021). They explained that they were compelled to night watch to protect their crops from the Blue Bull/Nilgai (*Boselaphus tragocamelus)* every night during the crop season on a rotation basis by the family members. When they spot lions resting surrounding/in their crop fields, they became tensionless and return home with the satisfaction that Nilgai will not raid their crop. Because lions prey mainly on Nilgai and in case of loss of livestock local farmers get suitable compensation from the state government. This wonderful embedded ethos of nature-culture linkage of fringe people is supporting the in-situ Asiatic Lion conservation in the Gir National Park, Gujarat (Saha 2021). The objective was to search the innovative method and mitigation measure to address the Human Wildlife Competition derived from the population growth of the same landscape of the shared ecosystem. The hypothesis is that the solution of Human Wildlife Competition is hiding on the awareness, approach, technique, learning, acceptance, and application of the principle of Compassionate Coexistence by the human population in the shared ecosystem of wildlife habitat.

MATERIAL AND METHODS

Madarihat-Birpara Block under Alipurduar District was selected for population study of human, as Jaldapara National Park of wild animal habitat is situated in the same landscape (GPS location 26º41'29" N, 89º16'59" E) (Fig. 1 & 2). Census data of human population was collected from the internet (https://www.indiagrowing.com/West_Bengal/ Jalpaiguri/ Madarihat). Population data of one horned rhinoceros was collected from the Jaldapara Wildlife Division of the Jaldapara National Park, West Bengal through questionnaire. On a sample basis Chekamari and Khairbari villages of Madarihat-Birpara Block under Alipurduar District were selected as study area for field and household survey with the objective to get community feedback as a mitigation measure of Human Elephant Competition (HEC). Hidden solution of HEC with the objective to address population Growth in the same landscape of the shared Ecosystem was communicated to the local people through audio-visual aids.

Movement of One Horned Rhinoceros (*Rhinoceros unicornis*) was studied in non-invasive mode by following the foot trail. After the direction of the Principal Chief Conservator of Forests (Chief Wild Life Warden), West Bengal and specified method of Standard Operating Procedures (SOPs), the departmental 'Kunki' elephants were used in protection and patrolling duty. At 'Pilkhana' (resting place for departmental elephant) proper health care of the Departmental 'Kunki' elephants were taken on periodic and on required basis by the Veterinary Officer with the objective of unhindered protection patrolling for stray Rhinoceros by them. Health care/check-up observations of departmental 'Kunki' elephant were recorded in individual Service book along with food, medicine register for future need. The field staffs of the forest department were engaged in the protection patrolling duty along with the 'Mahout' or 'Mahabat' (rider/trainer/keeper of Departmental elephant), with the objective to study the movement of stray Indian Rhino from the safest distance. It was their routine work. Behaviour, movement, protection and driving of Rhino were studied based on totally non-invasive method. No direct wild animal handling was involved and therefore the study was not assessed by an animal ethics committee. All the methods utilized and procedures were conducted such that they were in accordance with the direction and guidance of the Chief Conservator of Forests, Northern Circle and Principal Chef Conservator of Forests, Wildlife and Chief Wildlife Warden, Directorate of Forests, Government of West Bengal.

RESULTS AND DISCUSSION

During 10 years total human population of Madarihat-Birpara Block under Alipurduar District has been increased from 185499 (census of 2001) to 202026 (census of 2011) with the recorded population growth of 8.91%. Likewise estimated population of one horned Rhinoceros (*Rhinoceros unicornis*) of Jaldapara National Park in the same administrative block also has been increased from 237 (2019) to 292 (2022),with growth of 23.20% (Table 1).

The increase of population of wild animal on human population increase is very meagre but population growth of wild animal on the human population growth is significant in the same landscape of the shared ecosystem of Madarihat-Birpara Block under the Alipurduar District of West Bengal (Table 1). Excluding National Park area, human population density in 352.89 km^2 area of Madarihat-Birpara Block also increased from 525.66 to 572.49/km^2 . Rhino population density in 216.53 km^2area of Jaldapara National Park also increased from 1.09/ to1.35/km^2 (Table 2).

Growth of human population though less significant, but density wise significance is much more than the Rhino population in the shared ecosystem of the same landscape with the perspective of competition for space and other natural resources like grasses, fodder trees, water etc. Apart from that, the fixed area of the National Park is also having huge number of other herbivores like profuse breeder Gaur (Indian Bison), Sambar Deer, Hog deer and Wild boar. All the herbivores in the same landscape are engaged with intra and interspecific competition for food and shelter. Carnivore like leopard is also there in the same landscape. Population of wild animal beyond the carrying capacity leads to stray in the adjacent human habitation. As on 14th January, 2022 movement of one greater one-horned Rhinoceros or Indian Rhino had occurred from it's habitat of Jaldapara National Park to the adjacent landscape of Patlakhawa Protected Forest (GPS location 26º26'29" N, 89º20'0'46" E), surrounded by populated fringe villages of Coochbehar

Table 1. Comparison of population growth (Human vs. One horned rhinoceros)

Block	District and State	Species	Year of census/ population estimation	Population (Number)	Population growth (%)
Madarihat-Birpara	Alipurduar of West Bengal	Human	2001	18,5499	8.91
		Human	2011	202026	
		One horned rhinoceros	2019	237	23.20
		One horned rhinoceros	2022	292	

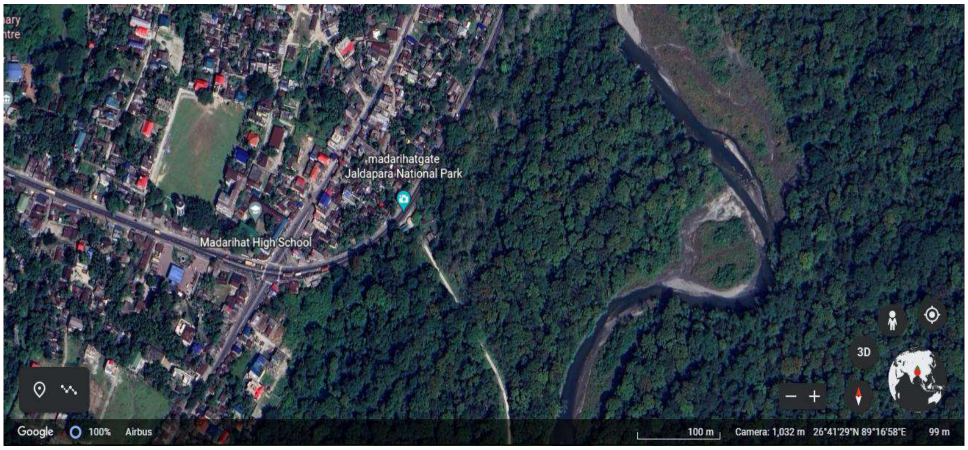

Fig. 1. 3D Satellite imagery of the human habitation of Madarihat-Birpara Block adjacent to Jaldapara National Park

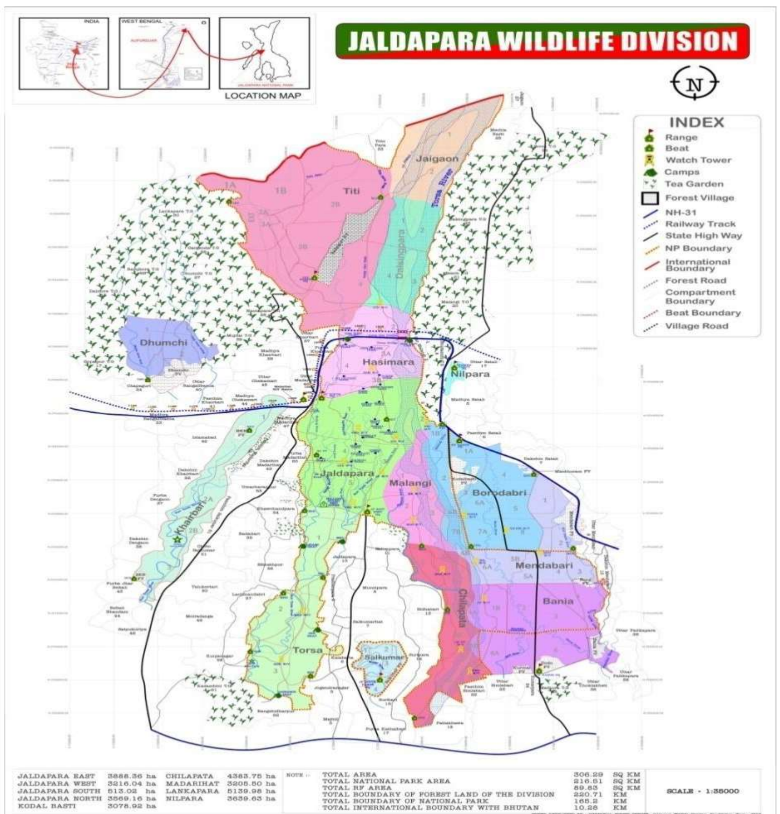

Fig. 2. Madarihat and adjacent Jaldapara National Park Landscape of that ecosystem (Source: Jaldapara Wildlife Division)

Table 2. Population density of human and one horned rhinoceros

Species	Year of census/ population estimation	Habitat area (Km^2)	Population	Density (per Km^2)	Population increase (Individual/unit area)
Human	2001	352.89	185499	525.66	46.83
	2011		202026	572.49	
One horned rhinoceros	2019	216.53	237	1.09	0.26
	2022		292	1.35	

district of West Bengal (Fig. 3). Huge resources like 20 Departmental 'Kunki' elephants (Elephant of Forest Department) and their mahouts (rider, trainer, or keeper of departmental elephant), Patawalas (fodder collectors) were engaged for almost 1 month for the guided driving of one stray Indian Rhino towards Jaldapara with the objective to remove the apprehension of local people regarding Human Rhino Competition or interaction, including the apprehension of forest personnel of poaching (Fig. 6). But we were unable to drive away the Indian Rhino from Patlakhawa Protected Forest. That Indian Rhino stayed for almost 2.5 months up to the end of March, 2022 at the human surrounded small forest of Patlakhawa and returned back to Jaldapara National Park in his own way without injuring anyone. This kind of massive unsuccessful intensive driving of wild animal for a certain period from protected forest to protected area incurred huge monetary loss of public resources just to remove the psychic apprehension of fringe people to avoid any direct confrontation.

During the period of force driving of stray Rhino from Patlakhawa Protected Forest to Jaldapara National Park, another stray of one adult Leopard was observed as on 27th January, 2022 in the populated Kolabagan area, Subhaspalli of Coochbehar town at a house premises. Field foresters of the Divisional Forest Officer tranquilized and rescued that stray leopard within 2 hours. Mob was a limiting factor behind our rescue work. The linear distance through River line from Patlakhawa Protected Forest (PF) to Kolabagan area of Coochbehar is approx. 20.8 (Fig. 4) km. As per our field data base1 to 2 leopards were at Patlakhawa Protected Forest at that time. Through the Torsa River line Coochbehar town is approx. 37.73 Km away from Jaldapara National Park (NP) of Alipurduar District (Fig. 5). The current analysis, thorough scanning of Patlakhawa grass and wood land with the 10 Kunki elephant has compelled the Leopard to stray from Patlakawa Protected Forest to Coochbehar town. There is hardly any probability of straying of Leopard directly from Jaldapara National Park, Madarihat to Kolabagan, Coochbehar town, as because Patlakhawa Protected Forest is situated in between Jaldapara National Park and Coochbehar town. But through Torsa river line Patlakhawa PF is 2 to 3 Km away from Dhoidhoi Beat of Jaldapara East Range side of Jaldapara National Park. But rejected the probability of straying from Dhoidhoi Beat side also, because if stray may happen from there, then Leopard had to come at Patlakhawa Protected Forest through river line. No such kind of previous record was also available in this regard. It is well established that through scanning of Patlakhawa Protected Forest by the departmental elephant to drive away the single Rhino towards Jaldapara, actually leads to stray of Leopard in the Coochbehar town as negative externalities of force driving. The force driving of stray animal is not a solution. It involves expenditure of lots of resources and time and most of the time may or may not give successful desired results also. It is the same landscape that has been shared by both human and wild animal population. Learning of the arts and techniques of patience, compassion and co-existence can be an innovative strategy to address the human-wild animal competition arisen from the population growth in the same landscape of that ecosystem.

Besides, the fixed area of Jaldapara National Park is also accommodating approx. 135-150 wild elephants. As per the previous study in the same landscape of Jaldapara National Park-Madarihat in between 2015-2018 there were 12 elephant deaths mostly by anthropogenic causes and 34 human deaths caused by the wild elephants (Saha 2020). The results of that study indicate that most of the direct encounter occurred at early morning and evening, when

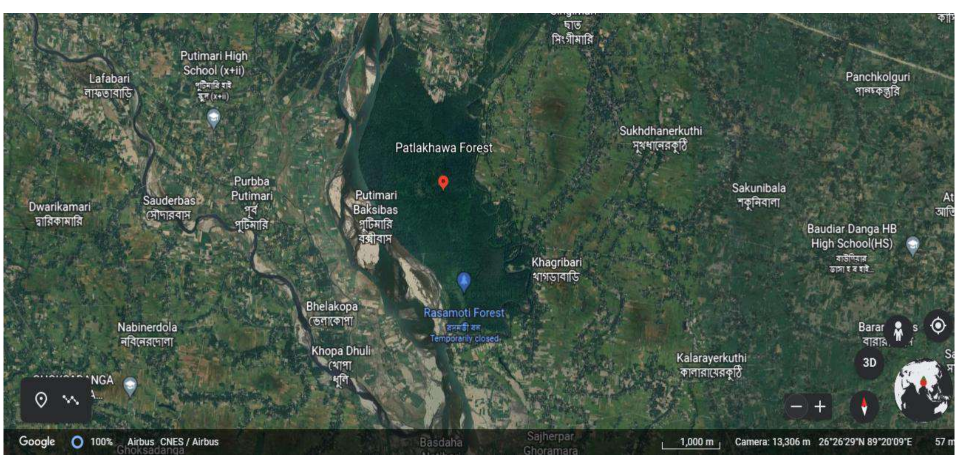

Fig. 3. Patlakhawa Protected Forest of Coochbehar District, West Bengal (One of the study sites) (Source: Google earth 3D imagery)

Fig. 4. Linear distance through River line between Patlakhawa Protected Forest to Kolabagan, Coochbehar town

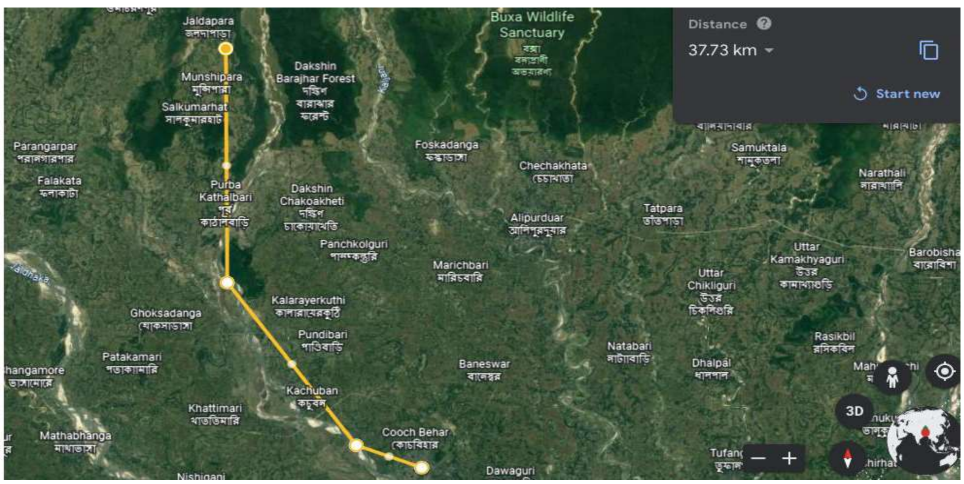

Fig. 5. River line distance between Jaldapara NP to Coochbehar town through Patlakhawa Protected Forest

Fig. 6. Unsuccessful effort of driving of stray Rhinoceros from Patlakhawa to Jaldapara National Park with the help of 'Kunki' elephant (Photo credit: Sanjit Kumar Saha)

people were gone for open defecation. Saha (2020) also supporting the findings that learning and acceptance of co-existence with the avoidance of direct interactions and confrontations through innovative implementable interventions are the keys to resolve the Human-Wildlife Competition in the same landscape of the shared ecosystem.

CONCLUSION

The solution of competition due to the pressure of population growth of human and wild animal in an ecosystem of the same landscape can be addressed by the awareness, approach, technique and learning of Compassionate Coexistence leading to Conservation. The local people can play a direct role in co-existence technique by staying in their houses at the time of stray of wild animal just to give a chance to the stray animal either to go in the forest in his own timely manner or to facilitate the rescue personnel of the Forest Department by not becoming as mob. Tranquilization, capture and translocation of stray wild animal may be a short-term goal to mitigate the competition between human and stray wild animal, but ultimate solution is hidden with the acceptance of principles and strategies of co-existence with the same landscape of shared ecosystem between wild animal and human. In this bio-diverse world growing population of both the species human and wild animal in a same landscape demands space, shelters and rights over natural resources of the shared ecosystem, naturally it leads to competition and only way out is adoption of strategies of coexistence without confronting one another. We human beings as an apex species of this biological clock have to play a major role in coexistence for the greater cause of compassion, conservation and existence of all the living forms on the earth.

Ethics statement: Behaviour and movement of wild animal was observed in non-invasive mode from a safest distance. All the methods were carried out in accordance with relevant guidelines and regulations. All the operation performed as per the traditional procedure of the field forestry and wild life management of the Directorate of Forests, Government of West Bengal.

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