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Assessment of morphological attributes of Guava tree for design of a novel tunnel spraying system

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ABSTRACT

The morphological attributes play a significant role in determining the level of applied insecticide by the existing spraying system. Therefore, this attempt was made to assess the various morphological attributes of guava tree such as leaf size, leaf area, leaf area index (LAI) and leaf area density (LAD). In this study, two leaf area estimation techniques (grid count method and Image processing technique based on ImageJ software) were compared and also estimate LAI and LAD for ten trees. An average leaf area was registered 29.56 cm^2 and R^2 value (0.98) for predicting leaf area by image processing technique. The LAI and LAD varied from 0.69 to 2.17 m^2/m^2 and 0.53 to 1.89 m^2/m^3, respectively. In addition, minimum and maximum LAD (mean ± SD) for zone wise ranged from 0.07 ± 0.06 m^2/m^3 to 2.73 ± 1.43 m^2/m^3, respectively. The study findings provide an opportunity to deal with large volume of leafs for leaf area estimation and would also help in design of various sprayers like determining the dimensions of tunnel sprayer and allow them to test in laboratory conditions with simulated artificial tree.

Introduction

Guava orchards occupy a prominent place among the orchards in India. Nowadays, the small guava canopy to be maintained through regular seasonal pruning is also increasing day by day. However, guava crops require a lot of pesticide applications to control the pest infestation and disease occurrences. The degree of crop protection from insect pest depends on effective insecticide application of any spraying system, but the performance of these spraying system in term of spray deposition, penetration of spray droplets and pesticide application rates is significantly affected with morphology of the crops as reported (Ade *et al.* 2007; Singh *et al.,* 2022). Various spraying techniques, such as air blast, vertical boom, tunnel spraying, etc., are being used in orchard crops. However, the performance of these sprayers was improved by testing them with different aspects of air assistance and spray quality as per reported by various researchers (Pergher & Petris, 2009; Celen *et al.,* 2009; Pezzi & Rondelli, 2000; Cross *et al.,* 2003; Molari *et al.,* 2005; Panneton *et al.,*2005; Pergher, 2005; Pergher, 2006; Pergher & Petris, 2008; Ade *et al.,* 2007; Jamar *et al.,* 2010). However, in the spraying systems, appropriate setting of various parameters like nozzle to nozzle

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spacing, nozzle orientation, operating pressure, air-jet orientation, air assistance, tunnel shield height, shield width as per existing morphology characteristics of the orchard crop effect the level of spray efficacy and efficiency of these sprayer. Hence, there is need to understand the morphological characteristics of a particular orchard crop. Thus, this study was conducted to estimate various morphological parameters such as leaf size, leaf area, leaf and branch orientation, leaf area index and leaf area density of a guava orchard for effective design of tunnel spraying system.

Material and Methods

In this study, ten trees were randomly selected, 1.5 years old from Guava orchard (L-49) at Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh. The various morphological characteristics were assessed for these guava trees as discussed below.

Overall canopy dimension of tree

Overall canopy dimension means the height, width, and length of the tree canopy, which were measured using inch tape. The width of the trees was considered across the direction of travel, while length was along the direction of travel. The canopy range was calculated by subtracting the distance of the tree's leaf above ground from its total height.

Determination of leaf characteristics

One branch was selected from ten guava trees in each direction i.e. The North, The East, The South, The West. Each branch was classified into three parts, first: 0-150 mm, second: 150-300 mm and third: beyond 300 mm. The measurement was done from the main stem of the tree (inner to outside from main stem) and then one leaf randomly collected from each part of every branch to avoid biasness. The measurement of 120 leaves (total sample size) was accomplished using a Vernier caliper. The width of the leaves was measured from end-to-end between the widest lobes of the lamina, while length was from the tip of the leaf to end of the petiole.

Determination of leaf and branch orientation

Leaf and branch orientation effect total leaf exposed area to spray application. In addition, the deposition, uniformity and spray liquid penetration at centre and canopy periphery depend on the orientation of the leaf and branch. Therefore, a sample of hundreds of both leaf and branch were randomly selected and measured using a universal bevel protector as shown in figure 1a and figure 1b. The value of both leaf orientation and branch orientation were noted down from the magnifying glass for each leaf and branch.

Estimation of leaf area

Leaf area reflects the health of orchard canopy. For the measurement for leaf area, two leaf area estimation techniques were used first, grid count method and second, image processing technique. The leaf area results from these two methods were compared for selected leaf sample to determine their accuracy.

Grid count method

In this study, a grid count standard method was used for leaf area estimation for 60 guava leaves sample by considering as a reference of following researchers (Rico-García *et al.,* 2009; Shivling *et al.,* 2011; Chaudhary *et al.,* 2012).

Image processing technique

ImageJ software was also used to estimate the leaf area for comparison purpose. Hence, same sample size was analysed in image J software using proper setting scale on the magnified image as shown in figure 2 and with "Hole fill" tool as followed by Singh *et al.,* 2022.

Leaf area index (LAI)

This index represents the ratio of the total leaf area of all leaves to ground area to be covered by canopy of that tree (Celen, *et al.,* 2009, Perhger and Zucchiatti, 2018), in which total leaf area includes area of all leaves, while ground surface area is estimated by multiplication between row to row spacing and plant to plant spacing. In this study, LAI was estimated for three major zones of ten trees such as top, middle and bottom zone. The top, middle and bottom zone varied from 1.5 to 2.0 m, 1.0 to 1.5 m and 0.5 to 1.0 m of tree height, respectively.

(a) (b)

Figure 1: Measurement of vertical angle (α) of leaf (a) and branch (b).

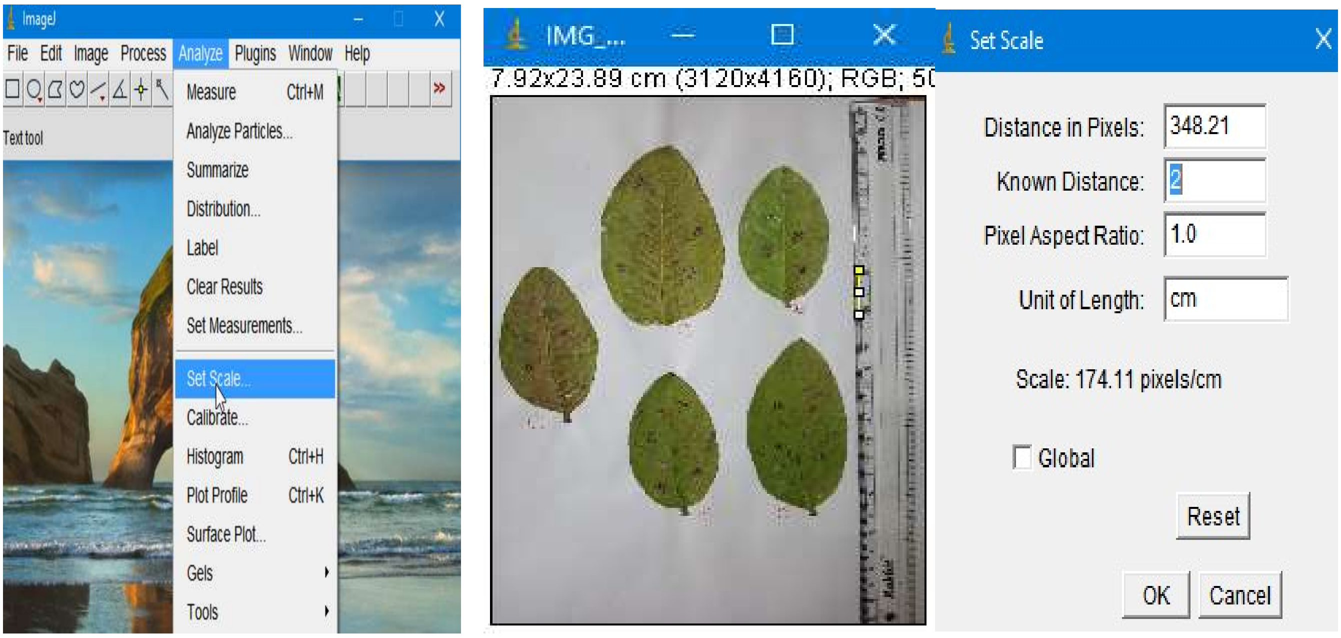

Figure 2: Scale setting in ImageJ software

Leaf area density measurement (LAD)

It represents an actual canopy volume of the tree and plays a crucial in the droplet deposition, penetration and recycling rate of spray liquid. The higher LAD restricts the penetration and recycling rate of the spray liquid, encouraging the infestation inside the canopy and wastage of the pesticide. In this study, a laboratory test rig (2×2×2 m) size, tree height was divided into 15 zones with MS wire, and cuboids across tree width using normal thread is shown in figure 3 (a), (b), and (c), respectively. However, the comprehensive methodology for calculation of LAD for all trees was adopted as used by Singh *et al.,* (2022).

(a) (b) (c)

Figure 3: (a) A laboratory set up (2×2×2 m) size; (b) Tree height divided into 15 zones with MS wire; (c) Cuboid across tree width using normal thread

Results and Discussion

Overall dimensions of guava tree canopy

Overall canopy dimension (height, length and width of canopy) of ten selected guava trees are given in table 1. The height of tree varied from 0.45 to 2.05 m. while, the range of the canopy varied from 0.90 m to 1.45 m (Height between lower and upper most leaf of each tree). The minimum height of the branches in the trees was recorded as 0.5 m. The width of the tree canopy varied from 1.05 m to 1.6 m, which could be used to decide tunnel opening of tunnel spraying system.

Leaf characteristics

The obtained data of leaves at different parts of sub-branch is given in table 2. The maximum mean ± SD of width and length of the leaf was 49.1 ± 10.1 mm and 100.4 ± 19.4 mm, respectively. The mean of width and length of the leaf was found minimum at front portion of sub-branch as compared to initial part of same sub-branches. Since, leaf size is affected with its age, attack of insect pest and disease infestation, size of old leave is generally larger than young leaves. However, in this study, disease free leaves were chosen on the basis of physical appearance of the leave and considered for the evaluation. The maturity level of leaves is generally increased from front portion of sub-branch to initial part of same sub-branches, but there are some young leaves, which appeared later on initial portion of the sub-branch and ignored in this study on the basis physical appearance. Usually, appearance of the old leaves is hard as compared to new leaves. In addition, the ratio of width to length of the leaves was found close to 0.5 in all cases. This ratio could be used in constructing the artificial leaf for development of artificial tree because simulated artificial tree canopy is required for laboratory experimentation and testing various types of sprayers.

Leaf and branch orientation

The frequency analysis was carried out to classify numbers of leaves in to a particular orientation group as shown in table 3. It demonstrated that majority of leaves had an orientation in between 30 to 60 degrees with horizontal plane. However, the leaves appear on the branch at certain angle and branch orientation with reference to main stem of the tree determines actual leaf surface exposure to the spraying system. Hence, it becomes important to know both leaf and branch orientation, which could be used for determination of the nozzle position in actual field conditions. It would assist in higher spray deposits and minimum pesticide wastage.

Table 1: Canopy dimensions of selected guava trees

Tree	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
H_{min}, m	0.75	0.5	0.55	0.60	0.80	0.55	0.65	0.45	0.45	0.55
H_{max}, m	1.80	1.95	1.97	1.74	2.05	1.95	1.75	1.60	1.58	1.45
Range, m	1.05	1.45	1.42	1.14	1.25	1.40	1.10	1.25	1.13	0.90
Width, m	1.5	1.00	1.38	1.36	1.60	1.28	1.08	1.25	1.25	1.05
Length, m	1.7	1.50	1.00	1.54	1.75	1.05	0.85	1.15	1.02	0.88

H_{min}: minimum height; H_{max}: maximum height, T_i: T (tree) and i (number's tree) i.e. 1, 2, 3…..10

Table 2: Leaf characteristics

Sub-branch	Width of leaf, mm	Length of leaf, mm	Width/Length
0-150	39.8 ± 5.5	80.3 ± 14.4	0.50 ± 0.08
150-300	44.4 ± 7.4	91.1 ± 13.9	0.49 ± 0.05
>300	49.1 ± 10.1	100.4 ± 19.4	0.49 ± 0.06

0-150 mm: front part of sub-branch; 150-300 mm: middle part of sub-branch and >300 mm : initial part of the sub-branch

Table 3: Leaf orientations and its frequency

Leaf angle, degree	Frequency of leaves
0-10	2
10-20	3
20-30	9
30-40	11
40-50	44
50-60	31

Branch orientation

A bar graph was plotted between branch orientation and number of branches as given in figure 4. It indicates that 79 % of the guava branches formed angle of 55 to 85 degree with horizontal plane. In addition, the highest number of branches formed branch angle in range of 65 to 75 degrees. Branch orientation affects the leaf area exposure to spraying system by changing the movement and position of the leaves with respect to movement of the spraying system. Hence, this information might be used for adjustment of the position and orientation of spray nozzles of the spraying system. Ideally, nozzle orientation should be perpendicular to surface of the leaf, which provides better spray deposits, uniform coverage and minimum wastage of costly pesticide.

Leaf area analysis

A graph was plotted between leaf area observed by grid count method and leaf area predicted by Image processing technique as shown in figure 5. In comparison to the grid count method leaf area results, the coefficient of determination (R^2) was found 0.98 for image processing methodology. It indicates that good predictability of the image processing technique for leaf area estimation with fast and simple methodology. However, an average leaf area was 29.56×10^4 mm^2 with standard deviation (6.63), but negative error revealed that image-based technique gives an average higher leaf area results as compared to standard grid count method as shown in table 4. The similar negative results are also reported by several researchers (Singh *et* 2021a, 2021b), but their results was based on comparison between grid count and mobile application based leaf area techniques. However, the leaf area of the tree influences the performance of the tunnel sprayer, higher leaf area generally allows more spray deposits on the peripheral canopy of the tree, but extreme dense canopy reduce spray penetration of spray liquid at the center of the tree to be delivered by the sprayer.

Leaf area index (LAI)

The leaf area index for ten trees' zones is given in table 5. In most of the trees, the higher leaf area index was recorded in the intermediate zone. Mean leaf area index (LAI) of the trees ranged from 0.23 to 0.92, with a standard deviation ranging from 0.20 to 0.66. Average LAI and standard deviation of the LAI in three zones of tree (upper to lower) varied from 0.19 to 1.09 and 0.16 to 0.46. The mean and standard deviation of the number of leaves and leaf area index for each zone of the tree is shown in table 6.

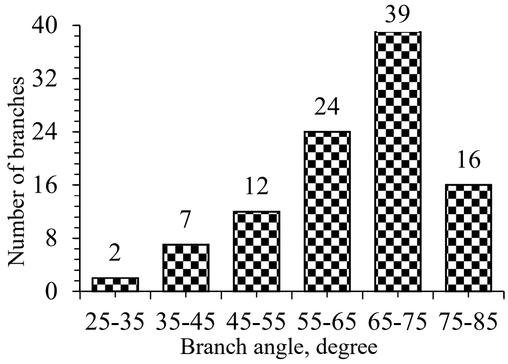

Figure 4: Orientation of the branch from horizontal in guava tree

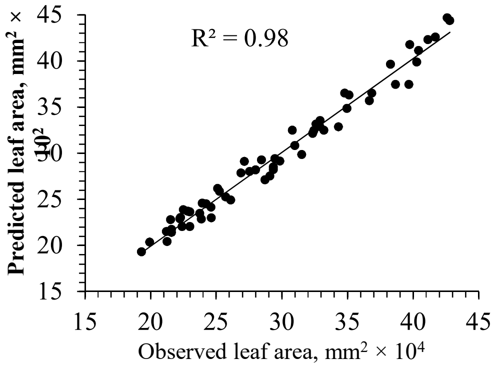

Figure 5: Predicted leaf area by image processing technique *vs.* observed leaf areas

Table 4: **Comparison between standard grid count method (SCM) and (IPT)**

Particulars	Standard Grid count $\times 10^2$ mm²	Image processing technique (IPT) $\times 10^2$ mm²	Error % (IPT)
Mean	29.56	29.65	-0.23
SD	6.63	6.97	3.41
r	—	0.99	—

SD: standard deviation

It indicates that the average leaf area index of middle zone was found highest as compared to other major zones, which depicts that guava tree is wider and thicker at middle zone. It also represents the presence of higher number of the leaves at middle of the canopy with reference to same ground area. It showed that there is a need to place more number of spray nozzles in spraying system with reference to middle of the tree canopy. It might help to improve spray deposits in the tree canopy, consequently provide better degree of protection from the insect pest attack and diseases infestation.

Leaf area density (LAD)

In this study, the LAD was calculated by counting of the number of leaves in each produced cuboidal zone and volume of that cuboidal zone for each tree. In zones Z_1 and Z_7, the maximum and minimum mean LAD of all trees was recorded as 0.07 and 2.73 m^2/m^3, respectively as given in table 7. From the top to middle zone of the trees, the variation in mean and standard deviation surged, and then decreased from middle to bottom zone of the trees. The leaf area density (LAD) was plotted against tree height for one and half year-old selected guava trees as presented in figure 6. It shows that LAD was highest at middle of the canopy and lowest at the top and bottom. LAD was increased from top to middle zone and then decreased from middle to bottom zone in all trees. The higher leaf area density was observed in between 1.0 m to 1.7 m tree height in all cases, except tree 5. However, all trees were exhibiting more or less same LAD pattern. Leaf area density (LAD) is generally used to indicate the health of crop. These morphological parameters of plant canopy directly affect the behavior of spray droplets on plant leaf surface in terms of deposition, droplets uniformity and spray droplets penetration. Hence, these parameters were assessed, which could be used for designing of tunnel spraying system such as nozzle to nozzle spacing, nozzle orientation. In this study, these parameters were calculated by following manual procedure as suggested by Singh *et. al.,* (2022). This research revealed that LAD found higher at middle zone as compared to bottom and top zones of all guava trees. It suggests that guava tree canopy generally follow parabolic shape on both right and left side of the tree. Similar findings related to canopy development have been reported by several studies (Hosoi and Omasa, 2006; Kamoske *et al.,* 2019). However, the high LAD indicates the presence of large volume of leaves in tree canopy and vice versa. The obtained LAD data help to understand about density of the canopy volume for the selected trees, number of leaves and shape of tree canopy. LAD measurements played a significant role for yield prediction models. Predictive models can estimate potential yields by

Table 5: Leaf area index zone as per different zone of trees

Tree height	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Mean	S.D.
1.5-2.0 m	0.04	0.14	0.50	0.10	0.46	0.16	0.24	0.06	0.12	0.07	0.19	0.16
1.0-1.5 m	0.54	0.95	1.85	1.41	0.42	0.71	1.61	0.90	1.51	1.00	1.09	0.46
0.5-1.0 m	0.12	0.71	0.41	0.47	0.02	0.21	0.24	0.32	0.70	0.32	0.35	0.22
Overall	0.69	1.81	2.17	1.98	0.90	1.08	2.09	1.28	2.32	1.39		
Mean	0.23	0.60	0.92	0.66	0.30	0.36	0.70	0.43	0.77	0.46		
SD	0.22	0.34	0.66	0.55	0.20	0.25	0.65	0.35	0.57	0.40		

T_i: T represents tree number; SD: standard deviation; 1.5-2.0m: top zone; 1.0-1.5m: middle zone; 0.5-1.0m: bottom zone

Table 6: Average numbers of leaf and LAI

Tree height	Number of leaves	LAI
1.5-2.0 m	109.1 ± 122.5	0.19 ± 0.16
1.0-1.5 m	542.1 ± 215.61	1.09 ± 0.46
0.5-1.0 m	172.5 ± 112.85	0.35 ± 0.22

Table 7: Average LAD zone wise of ten trees

Zones of tree	Leaf area density (Mean ± SD)
Z_{15}	0.08±1.00
Z_{14}	0.17±0.22
Z_{13}	0.28±0.30
Z_{12}	0.56±0.58
Z_{11}	0.79±0.51
Z_{10}	1.39±0.73
Z_9	1.99±0.90
Z_8	2.36±1.28
Z_7	2.73±1.43
Z_6	2.39±1.17
Z_5	1.72±0.98
Z_4	1.08±0.81
Z_3	0.41±0.33
Z_2	0.22±0.17
Z_1	0.07±0.06

Mean LAD in m^2/m^3; SD standard deviation

Table 8: Overall leaf area density for one and half year guava trees

Trees	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
No. leaves	596	917	1292	1402	850	491	648	624	981	436
Total leaf area, m^2	1.77	2.72	3.83	4.16	2.52	1.46	1.92	1.85	2.91	1.29
Tree volume, m^3	3.32	2.18	2.03	2.60	4.20	2.24	1.15	1.73	2.10	0.88
LAD, m^2/m^3	0.53	1.25	1.89	1.60	0.60	0.65	1.67	1.07	1.39	1.47

LAD: leaf area density, m^2/m^3

quantifying the leaf area density in a field, along with other relevant parameters such as crop variety and environmental conditions. It also influences the design and optimization of types of machineries, where design must be based on the different characteristics of the plant's morphologies and LAD. Then, machinery will effectively handle the crop with minimum plant damage. Total number of leaves for ten selected guava trees (1.5 years old) varied from 436 to 1402 and total leaf area range from 1.77 to 4.16 m^2. It was happened due to the role of many factors such as variation in nutrient availability to each tree. For total area estimation, average leaf area was used about 29.56×10^2 mm^2 per leaf (average leaf area of 60 leaves sample). However, maximum and minimum overall leaf area density for ten trees was found 1.89 and 0.53 m^2/m^3 as shown in table 8. Morphological understanding of any orchard crop is important for following purposes such as designing and development of crop harvesting machine and their effective operation in orchard for better disease or insect pest management. Hence, in this study, the morphological characteristics such as leaf attributes, leaf and branch orientation, leaf area, leaf index, leaf area density for 1.5 year old guava were measured. However, there are many methods available to estimate leaf area such grid counts standard method, leaf area meter device, algorithm based application, regression model, but major concern is accuracy, time and cost for all these technologies. Therefore, ImageJ software technique was used to test its accuracy in comparison to grid count standard method. The study revealed that the correlation coefficient (r) between obtained leaf area results from image processing technique and grid count method was 0.99, which ensure accuracy of the image processing technique i.e. supported by following researchers (Rico-Gracia *et al.*, 2009; Patil and Bodhe, 2011; Shivling *et al.* 2011; Chaudary *et al.,* 2012). Fascella *et al.* (2013) has used non-destructive portable scanning planimeter for leaf area estimation and reported quick leaf area results and high accuracy, but also highlighted device feasibility only for small plant.

Conclusion

From obtained results of various morphological parameters such as leaf area, leaf size, leaf area index (LAI) and leaf area density (LAD), it could be concluded that guava tree canopy follow a particular trend, which might be useful for design purpose of any spraying system. This study showed that guava tree canopy is generally wider and thicker at the middle as compared to top and bottom of the tree. It might be useful for nozzle spacing and nozzle orientation adjustment in spraying system in field condition, which would facilitate better spray deposition and ensure greater degree of crop protection from insect.In this study, an average leaf area per leaf and ratio of width to length of leaf was recorded about 29.65×10^2 mm^2 and0.5, respectively. It might be used for development of artificial tree for experimental purpose in laboratory conditions. The image processing technique showed higher predictability of leaf area estimation with 0.98 R^2 value, which ensure fast and easy leaf area estimation with higher accuracy.

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Conflict of interest

The authors declare that they have no conflict of interest.

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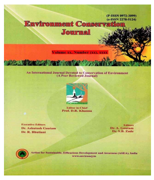

Effect of weed management practices on growth dynamics and productivity of rainfed pearl millet under conservation agriculture

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ABSTRACT

An experiment was conducted on rainfed pearl millet at ICAR- IARI, New during the *kharif* season of 2019, in a split-plot design with three replications. tillage practices, viz. Conventional tillage (CT), Zero tillage and Zero till Residue@ 3t/ha (ZT+R) were evaluated in the main plot and seven weed manag treatments, viz. weedy check, hand weeding (HW) at 30 and 50 days after s (DAS), atrazine @ 0.75 kg/ha(PE) *fb* 2,4-D @0.75kg/ha (PoE), atrazine @ 0.75 PE, atrazine @ 0.75 kg/ha PE *fb* tembotrione @ 0.05kg/ha PoE, atrazine @ 0.75 PE *fb* tembotrione @ 0.075kg/ha PoE, atrazine @0.75 kg/ha PE *fb* tembotrio 0.10 kg/ha PoE. ZT+R 3t/ha resulted in enhanced growth attributes, and highe uptake which led to increased grain yield. Among weed control treatments, weeding (HW) twice at 30 and 50 DAS along with the integration of pre-eme application of atrazine 0.75kg/ha *fb* 2,4-D 0.75kg/ha PoE and tembotrione, kg/ha or 0.1 kg/ha PoE resulted in better growth attributes which signifi resulted in higher grain yield under rainfed conditions of semi-arid tropics.

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br. emend Stuntz] is an important crop of the arid and semi-arid climate of the world with a greater ability to withstand harsh environments. It is the sixth most important global cereal crop grown in the rainfed areas of India**.** In India, it forms a staple diet of the majority of poor farmers and is a multipurpose cereal crop for grain and green fodder for livestock. India is the largest producer of pearl millet covering marginal and sub-marginal land of rainfed areas. It is grown in an area of 7.41 million hectares with productivity of 1391kg/ha while a production estimate of 9.35 million tonnes (Directorates of millets development, 2021-22). However, the productivity of pearl millet is far less (1t/ha) than its potential (3t/ha) due to several constraints such as low and erratic availability of soil moisture, depleted soil fertility, and severe weed infestation. Tillage systems intensified with mechanization have played a crucial role to meet the growing demand for food grains for the burgeoning global population. But extreme tillage practices have many objectionable effects on soil and water such as the formation of hardpan due to soil compaction, advancing soil erosion, degradation of soil structure, reduction of soil organic matter, depleting soil properties and water holding capacity etc., resulting in low and unstable crop production (Bronick and Lal, 2005; Ramos *et al.,* 2011; López-Garrido *et al.,* 2012). Conservation agriculture offers an encouraging alternative to conventional agriculture and outperforms traditional tillage problems such as soil fertility decline, moisture stress, low and unstable crop yields and high cost of production. Weed stress increased in the early years of conservation agriculture implementation, by cause of eliminating tillage as a weed control mechanism. Being a warm rainy season crop, pearl

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millet encounters severe weed competition leading to a heavy reduction in grain yield. They emerge and compete with the crop for nutrients, moisture, light, and space, which can reduce yield by as much as 16-94% (Balyan *et al.,* 1993), 41% (Girase *et al.,* 2017), and 35% (Nibhoria *et al.,* 2021). The nutrient depletion by weeds in pearl millet is up to 61.8 kg N, 5.6 kg P and 57.6 kg K/ha (Ram *et al.,*2005). Under such occurrences, effective and economic weed management practices are of foremost importance to attain efficacious control of weeds in pearl millet crops and achieve their productive potential with better soil and crop management. Therefore, a study was carried out to assess the effect of weed management on growth dynamics and productivity of rainfed pearl millet under conservation agriculture.

Materials and Methods

A field experiment was conducted at ICAR-IARI, New Delhi, India during the *kharif* season of 2019 under a sandy loam texture with 7.5 pH. During the crop duration (July-October), the mean minimum, maximum temperature, relative humidity and total rainfall ranged from 31-36.5°C, 21.8-28°C, 33-98%, and 780 mm. The NPK status of soil were 0.03 kg/ha,12 kg/ha,175 kg/ha and OC content 0.34%. The experiment was laid out in a split-plot design having 21 treatment combinations with 3 replications. Three tillage practices: conventional tillage (CT), zero tillage (ZT), zero tillage with residue 3t/ha (ZT + R) were assigned to the main plot and sub-plots received seven weed management practices: weedy check (WC), hand weeding (HW) twice at 30 and 50 days after sowing (DAS), pre-emergence application (PE) of atrazine 0.75 kg/ha followed by (*fb*) post-emergence application (PoE) of 2,4-D 0.75 kg/ha at 30 DAS, atrazine 0.75 kg/ha PE, atrazine 0.75 kg/ha PE *fb* tembotrione 0.05 kg/ha PoE at 30 DAS, atrazine 0.75 kg/ha PE *fb* tembotrione 0.075 kg/ha PoE at 30 DAS, atrazine 0.75 kg/ha PE *fb* tembotrione 0.10 kg/ha PoE at 30 DAS. In the previous *rabi* season, the barley crop was sown as a uniform crop and the residue@ 3t/ha was retained on the soil surface after sowing in the respective treatments of the experiments. Pearl millet (Pusa composite-443) was sown at the seed rate of 5 kg/ha at a spacing of 50 cm × 10 cm on 16th July 2019. The full dose of P_2O_5 (40 kg/ha), K_2O (40 kg/ha) and half dose of N (30 kg/ha) was applied as basal at the time of sowing. The remaining N (30 kg/ha) was applied in two equal splits at 25 and 50 DAS prior to rainfall as N might subject to leaching. Pre-emergence application of atrazine was done one day after sowing. The post-emergence herbicides, 2,4-D and tembotrione were applied at 30 DAS. First hand weeding was done manually at 30 DAS in the respective plots of the treatments and the second HW was done at 50 DAS. Nitrogen (N) content was estimated by the modified Kjeldahl method (Prasad *et al.* 2006), while P and K concentrations were determined using a sulfuric–nitric–perchloric acid digest (Prasad *et al.*2006). By multiplying the nitrogen content of grain by the factor 6.25, the protein content of grain was calculated (A.O.A.C., 1970). The growth attributes of the crop were recorded at 30 and 60 DAS, and yield at harvest using standard procedures.

Results and Discussion

Growth attributes

The most common grassy weed species identified in the experimental field were *Cynodon dactylon*, *Echinochloa colona*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Bracharia ramose*, and *Bracharia eruciformis*. Only two species, *Cyperus rotundus* and *Cyperus iria*, were classified as sedges, whereas *Commelina benghalensis*, *Trianthema portulacastrum*, *Digeria arvensis*, *Amaranthus viridis*, and *Parthenium hysterophorus* were found to be dominant broadleaved weed species.The observation showed that zero tillage + residue 3t/ha (ZT+R) had a promising effect on growth parameters at 30 DAS and 60 DAS compared to zero tillage (ZT) and conventional tillage (CT) (Table 1).Plant height (66.1 and 252.1 cm), number of tillers (1.9 and 2.7cm), leaf area index (2.3 and 5.4), dry matter accumulation (186.8 and 696.1 cm) were all significantly higher in zero tillage + residue 3t/ha (ZT+R) followed by zero tillage (ZT) treatment with plant height (62.4 and 239.9cm), number of tillers (1.7 and 2.4 cm), leaf area index (2.2 and 4.8), dry matter accumulation (174.4 and 638.6 g/m^2) at 30 and 60 DAS respectively (Table 1).ZT + R 3t/ha enabled the crop plant to withstand minimal competition, resulting in improved crop growth and growth parameters. This can be attributed to the allelopathic effect of barley residues by exuding gramine, hordenine, and phenolic compounds in ZT+R, which suppressed the weeds by forming a physical barrier and overall weed suppressive effects. There is an increase in the microporosity in zero tillage soils by increasing the storage pores (0.5-50mm) and the number of elongated pores (50-500mm) which consequently increased the available water for plants (Pagliai *et al.,*2006). Furthermore, the retention of crop residue raised the soil moisture which ultimately enhanced the growth and biomass production of crops both directly and indirectly by augmenting the bio-availability, and efficient utilization of applied and endemic nutrients (Singh *et al.,*2018). Among the weed management practices, growth parameters like plant height, number of tillers/m^2, leaf area index and dry matter accumulation at 30 DAS were registered as significantly higher than those of the treatments receiving the pre-emergence application of atrazine 0.75 kg/ha over rest of the treatments (Table 1). Plant height was recorded highest (66.4 cm) in atrazine@ 0.75kg/ha (PE) *fb* tembotrione @ 0.075 kg/ha (PoE) at 30 DAS, and at 60 DAS it recorded highest (251.8cm) in hand weeding (HW) at 30 and 50 DAS (Table 1).

Table 1: Effect of weed management on growth attributes of CA based pearl millet

Treatments	Plant height (cm)		Number of tillers/m^2		LAI		DMA (g/m^2)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Main plot: Tillage								
CT	60.0	229.7	1.7	2.2	2.1	4.7	167.3	617.6
ZT	62.4	239.9	1.7	2.4	2.2	4.8	174.7	638.6
ZT + R 3t/ha	66.1	252.1	1.9	2.7	2.3	5.4	186.8	696.1
SEm±	0.8	4.2	0.03	0.05	0.17	0.08	3.5	15.3
LSD (P≤0.05)	3.2	17.1	0.13	0.71	0.04	0.30	14.1	62.0
Sub-plot: Weed management								
W_1	53.1	205.3	1.5	1.8	1.9	4.6	138.0	559.5
W_2	57.8	251.8	1.5	2.7	2.03	5.2	141.4	701.1
W_3	66.0	248.0	1.9	2.6	2.19	5.1	191.7	667.2
W_4	64.6	236.9	1.8	2.4	2.21	4.8	188.8	635.6
W_5	65.6	246.0	1.8	2.6	2.14	5.0	192.2	663.0
W_6	66.4	251.0	1.8	2.6	2.14	5.0	190.7	669.0
W_7	64.3	245.1	1.8	2.6	2.18	5.0	190.8	661.5
SEm ±	1.2	5.4	0.04	0.08	0.06	0.1	4.3	14.5
LSD (P≤0.05)	3.4	15.6	0.11	0.24	0.18	0.4	12.6	41.6

LAI: Leaf area index DMA: Dry matter accumulation DAS: Days after sowing
CT: Conventional tillage ZT: Zero tillage ZT+R: Zero tillage + Residue
W_1: Weedy check W_2: Hand weeding at 30 and 50 DAS W_3:Pre-emergence(PE) application of Atrazine@ 0.75kg/ha *fb* post emergence (PoE) application of 2,4-D 0.75kg/ha W_4:PE application of Atrazine@ 0.75kg/ha W_5:PE application of atrazine@ 0.75kg/ha *fb* PoE application of tembotrione @ 0.05 kg/ha W_6: PE application of atrazine @ 0.75kg/ha *fb* PoE application of tembotrione @ 0.075 kg/ha W_7: PE application of atrazine @ 0.75kg/ha *fb* PoE application of tembotrione @ 0.10 kg/ha

Similarly, number of tillers were recorded highest ($1.9/m^2$) in atrazine@ 0.75kg/ha (PE) *fb* application of 2,4-D 0.75kg/ha (PoE) and at 60 DAS recorded highest number of tillers (2.7) in HW at 30 and 50 DAS. Atrazine@0.75kg/ha (PE) had a greater LAI at 30 DAS (2.2), and HW at 30 and 50 DAS had the greatest LAI (5.2) at 60 DAS. Dry matter accumulation (DMA) recorded higher ($192.2 g/m^2$) in atrazine@ 0.75kg/ha (PE) *fb* tembotrione @ 0.05 kg/ha (PoE) at 30 DAS, and HW at 30 and 60 DAS reported higher DMA (701.1) at 60 DAS. Pre-emergence application of atrazine 0.75 kg/ha effectively controlled early emerging broad-spectrum weed flora by inhibiting photosynthesis.

Growth parameters were markedly influenced by different weed management practices. The maximum growth parameters were noted under two hand weeding at 60 DAS, which was significantly higher over the rest of the treatments. This could be attributed to a lower dry weight of weeds which led to less weed competition during the critical crop-weed competition period (30 and 45 DAS) and thereby better growth of pearl millet crop by sufficient availability of resources. The next best treatments were atrazine 0.75 kg/ha (PE) *fb* 2,4-D 0.75 kg/ha (PoE), atrazine at 0.75 kg/ha (PE) *fb* tembotrione 0.05 kg/ ha (PoE), atrazine 0.75 kg/ha (PE) *fb* tembotrione 0.075 kg/ha (PoE) and atrazine 0.75 kg/ha (PE) *fb* tembotrione 0.10 kg/ha (PoE) and recorded on a par with each other.

Nutrient uptake and protein content

Nutrient depletion by weeds revealed that maximum N, P and K depletion was under CT, whereas lowest N, P and K depletion was observed in ZT+R 3t/ha (Table 2). This could be attributed to residues on the soil surface which acted as a physical barrier to resources for weeds growth and indirectly increased their predation in zero tillage by providing foraging and nesting habitat for predators, resulting in less weed infestation due to restricted germination, growth and development (Chauhan *et al.,* 2012; Den Hollander *et al.,*2007), ultimately low nutrient depletion by weeds. The exponential growth of weed in weedy check treatment resulted in higher uptake of N, P and K nutrients. On the contrary, the minimum depletion of N, P and K/ha was observed with atrazine 0.75 kg/ha (PE) *fb* tembotrione 0.10 kg/ha (PoE) that was closely accompanied by hand weeding at 30 and 50 DAS and atrazine 0.75 kg/ha (PE) *fb* tembotrione 0.075 kg/ha (PoE) treatments. Reduction in N, P and K depletion under corresponding treatments could be ascribed to effective control of broad-spectrum weeds by manual weeding and integration with herbicidal treatments, which increased the nutrient and water availability for crop plants. On the other hand, greater biomass of weeds accumulated under weedy checks interfere with crop growth development might be the only reason for higher nutrient depletion. The treatment with zero tillage + residue 3t/ha (ZT+R) was notably superior in total uptake of NPK by pearl millet when compared to both the tillage treatments (Table 2). The lowest N, P and K uptake was recorded under conventional tillage (CT). This may be due to more weed suppression under ZT + R 3t/ha, leading to much better weed control, ensuing higher nutrient content and total nutrient uptake by the crop due to increased yield of the crop. Ali *et al.*(2006) reported that the lowest values of soil organic matter, N, P and K were recorded in conventional till plots due to the inversion of topsoil during ploughing which shifts less fertile subsoil to the surface in addition to possible leaching. Among weed management practices, two hand weeding at 30 and 50 DAS reported the maximum uptake, which was found at par with atrazine 0.75 kg/ha (PE) *fb* 2,4-D 0.075 kg/ha (PoE). Increased N, P and K uptake might be ascribed to better weed control and higher yield production (Ramesh *et al.,* 2019; Ram *et al.,* 2005). ZT+R 3t/ha with hand weeding at 30 and 50 DAS recorded the highest protein yield followed by that under atrazine 0.75 kg/ha (PE) *fb* 2,4-D 0.075 kg/ha (PoE) (Table 2). As the protein in grain is a function of its N concentration, hence the higher concentration of N in grain under superior treatments seems to be the only reason for attaining higher protein content. The favourable effect of weed control using two hand weeding at 20 and 40 DAS and atrazine at 0.5 kg/ha + one hand weeding at 20 DAS on protein in pearl millet has also been reported by (Singh *et al.,* 2006; Das *et al.,*2013).

Grain yield

Grain yield was significantly more under ZT+R (2.40 t/ha) as compared to CT (2.08) and ZT-R (2.18 t/ha) (Table 2). Retention of barley residues had a

Table 2: Effect of weed management on protein content, NPK uptake and grain yield of CA based Pearl millet

Treatments	Protein content (%)	Weeds(kg/ha)			Crop(kg/ha)			Grain yield (t/ha)
		N	P	K	N	P	K	
Main plot: Tillage								
CT	11.3	12.3	1.4	10.7	37.6	13.7	21.3	2.08
ZT	11.5	10.7	1.2	9.3	40.0	14.7	22.8	2.18
ZT + R 3t/ha	11.8	7.7	0.9	6.7	45.5	17.1	24.8	2.40
SEm±	0.02	0.2	0.03	0.2	0.6	0.3	0.6	0.04
LSD (P≤0.05)	-	0.7	0.1	0.7	2.1	0.9	2.0	0.18
Sub-plot: Weed management								
W_1	11.2	28.2	3.2	24.8	29.5	10.9	18.0	1.65
W_2	11.8	5.9	0.6	5.1	46.7	17.4	24.0	2.53
W_3	11.6	6.1	0.7	5.3	44.5	16.8	23.3	2.42
W_4	11.2	13.4	1.5	11.6	37.8	13.6	20.7	2.09
W_5	11.5	6.2	0.7	5.4	42.2	15.1	22.2	2.27
W_6	11.6	6.0	0.7	5.3	43.4	16.0	23.0	2.33
W_7	11.7	5.7	0.6	5.0	42.9	16.2	23.8	2.29
SEm ±	0.02	0.15	0.02	0.2	0.7	0.3	0.5	0.07
LSD (P ≤0.05)	-	0.4	0.05	0.4	2.1	0.8	1.7	0.22

CT: Conventional tillage ZT: Zero tillage ZT+R: Zero tillage + Residue
W_1: Weedy check W_2: Hand weeding at 30 and 50 DAS W_3: Pre-emergence(PE) application of Atrazine@ 0.75kg/ha *fb* post emergence (PoE) application of 2,4-D 0.75kg/ha W_4:PE application of Atrazine@ 0.75kg/ha W_5:PE application of atrazine@ 0.75kg/ha *fb* PoE application of tembotrione @ 0.05 kg/ha W_6: PE application of atrazine @ 0.75kg/ha *fb* PoE application of tembotrione @ 0.075 kg/ha W_7: PE application of atrazine @ 0.75kg/ha *fb* PoE application of tembotrione @ 0.10 kg/ha

synergistic effect on crop growth by improving the soil's physical, chemical and biological environment. Residue retention amends aggregate stability, reduces soil erosion, and increases soil macrofauna, which augments soil aeration and water infiltration, thus enhancing soil productivity. Furthermore, it directly increases the input of organic matter and nutrients into the soil, in turn improving soil nutrient availability for crop growth (Zheng *et al.*,2014). Hand weeding (HW) at 30 and 50 DAS was the best weed management practice in regards to grain yield followed by atrazine @ 0.75 kg/ha (PE) *fb* 2,4-D @ 0.75 kg/ha (PoE) at 30 DAS and atrazine 0.75kg/ha PE *fb* tembotrione 0.075 kg/ha PoE. Pre-emergence application of atrazine @ 750 g/ha *fb* HW at 30 DAS resulted in higher growth parameters which could be ascribed to weed-free conditions for a longer period during the crop ontogeny increasingthe availability of growth resources to the crop (Mishra *et al.,*2017). Additionally, the superiority of the integration of herbicides on yield-attributing parameters was attributed to better weed suppression at all the growth stages of the crop by pre-emergence and post-emergence application of herbicides. Girase *et al.* (2017) noted that the highest grain yield of pearl millet was obtained with pre-emergence application of atrazine 0.5 kg/ha + 1 HW at 35 DAS. Sharma *et al.* (2018) reported that the combined application of tembotrione with atrazine was significantly superior to its sole application, which considerably reduced weed density, dry weight, weed index, higher weed control efficiency, and increased values of growth, and yield attributes and yield of the crop.

Conclusion

Zero tillage + residue (ZT+R) 3t/ha with the use of two hand weeding (HW) at 30 and 50 DAS and a combination of pre and post-emergence application of herbicides proved their superiority in increasing all crop growth, lowest nutrient removal by weeds, highest nutrient uptake by crop which resulted in maximum productivity, which is of prime importance to achieve a higher yield of pearl millet under rainfed conditions of semi-arid tropics.

Conflict of interest

The authors declare that they have no conflict of interest.

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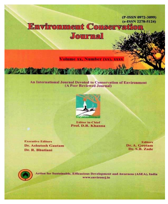

Antimicrobial activity of silver nanoparticles synthesized from *Wrightia tinctoria* fruit extracts

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ABSTRACT

Nanoparticles are synthesized by using various chemical methods in higher yields but they are not very environmentally friendly and have hazardous effects on living cells. This can be attributed to the overuse of hazardous chemicals involved in the process. The green approach of nanoparticle synthesis is widely gaining attention worldwide as it is considered as nontoxic, harmless and ecofriendly. Apart from this they also have multiple applications in various fields of science and technology. Nanoparticles synthesized by using various phytochemicals are also effective against a variety of microbial populations. The objective of this study is to synthesize silver nanoparticles (AgNPs) from the fruit extracts of *Wrightia tinctoria* and evaluating its antimicrobial capacities against gram-positive and negative bacterial strains. Silver nanoparticles were synthesized using different solvent extracts of *Wrightia tinctoria* pods. The formation of silver nanoparticles was noted by detecting the change in color of the solution. The presence of nanoparticles was detected by performing UV visible spectroscopy and monitoring the spectrum from 400 nm to 800 nm. A small peak at 425 nm suggested the presence of silver nanoparticles. In a later part of the study, the inhibitory effect of green synthesized silver nanoparticles on the growth of E. *coli* and *S. aureus was monitored.* The appearance of a zone of inhibition further confirmed the antimicrobial effect of the synthesized nanoparticles.

Introduction

NPs are fine and thin particles ranging between 1 and 100 nm in diameter (Mohanraj and Chen, 2006). This process involves the collection of atoms bonded together to form a structure with a radius less than 100 nm (Kumari, 2018). Metal nanoparticles ranging in size possess different shapes. Metal nanoparticles of Au, Ag, Zn, Pt, Pd, Se, Ti, Cu, etc., have been synthesized successfully (Khandel *et al.*, 2018). To make metal nanoparticles eco-friendly and in the quest for 'going green', various bioinspired methods for their synthesis have been employed. Biocompatibility and environmentally benign properties make green synthesized nanoparticles the preferred choice. Plant extracts carry a variety of biomolecules, such as amino acids and proteins, sugars, certain enzymes and other traces of metals. These metabolites are strongly involved in the bioreduction process. Plant materials also contain many phytochemicals, such as phenols, saponins, terpenes, alkaloids, and alcohol, which tend to reduce these metal salts (Adeyemi *et al.*, 2019). Due to the large surface area, the activity of the nanoparticles is enhanced. The green synthesis of nanoparticles can be an eco-friendly alternative for the production of nanoparticles. Natural plants have been verified to have dual effects, acting both as capping agents and reducing agents, thus improving the pharmacological effectiveness and constancy of

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NPs (Javed *et al.*, 2020). Plant-based nanoparticles are gaining attention worldwide due to their multiple applications in various fields of science and technology. They are synthesized from different plant extracts and are nonhazardous to the environment. In India, we have vast knowledge of ayurveda since ancient times, which includes information on hundreds of plants with medicinal properties (Pandey *et al.*, 2013). This knowledge is still being used by locals and medical practitioners to cure many health ailments. In the last few decades, the synthesis of plant-based nanoparticles (NPs) has attracted increased amounts of attention due to the ease of preparation. The ability of phytoconstituents to act as reducing agents has made their use attractive (Mittal *et al.*, 2013. Ankamwar, 2010). Research conducted worldwide indicates that plant-mediated nanoparticle synthesis methods progress via quick extra or intracellular processes (Husen, 2017). Most phytoconstituents are found in various parts of plants, such as leaves and flowers. They are also abundant in roots, fruits, and stems. Therefore, the use of different plant parts has been reported for the production of plant-mediated metal-based nanoparticles (Husen, 2017). NPs synthesized from several phytochemicals are powerful against a variety of microbial populations. The green synthesis of silver nanoparticles (SNPs) has been proven to have numerous applications in scientific fields and shows great potential for antimicrobial activity (for example, AgNPs) (Rai *et al.*, 2009) [10]. Silver nanoparticles (AgNPs) are among the most studied metal nanoparticles. Its unique features and physical and chemical properties have led to its diverse application in medicinal fields (Zhang *et al.*, 2016). Moreover, nanoscale silver particles exhibit a high surface-area-to-volume ratio (for which the size remains below 100 nm) and are of great interest due to their strong antimicrobial effects on both gram-positive and gram-negative bacteria (Morones-Ramirez *et al.*, 2013. Meroni *et al.*, 2020) viruses and other eukaryotic microorganisms (Gong, 2007) compared to other metals in their nanosized forms.

Wrightia tinctoria is the plant used for this study and belongs to the family *Apocynaceae*. The plant is found in hilly regions in India, Australia and Southeast Asia (Wrightia tinctoria - Wikipedia). It is a flowering plant, and its fruit show vast medicinal properties.

In this study, the focus was on the synthesis of silver nitrate nanoparticles by using *Wrightia tinctoria* fruit extracts and their effect on the growth of gram-negative and gram-positive bacteria such as *E. coli* and *S. aureus,* respectively.

Materials and Methods

The following methods and materials were utilized to synthesize silver nanoparticles and to evaluate their antimicrobial potential against gram-positive and gram-negative bacteria.

a. Selection of medicinal plants

Wrightia tinctoria, which belongs to the family *Apocynaceae,* was selected for this study due to its medicinal properties. This plant possesses a wide range of phytochemicals that have antimicrobial properties, and the use of green synthesis of AgNPs is still unexplored. The plant was collected from Gadchandur town located in Chandrapur district in Maharashtra, India (19°41'26"N 79°10'31"E). The pods of the plants were collected in October.

b. Preparation of plant extract:

The plants were fresh and washed with tap water and twice with distilled water. Later, the plants were shed and dried for 30-35 days at a temperature of approximately 37-40°C. These were then cut into pieces after weighing and boiled with a mixture of methanol and distilled water to obtain a dark-colored extract. Methanol (80 ml) and distilled water (20 ml) were mixed together and added to 7.24 g pieces of *Wrightia tinctoria* pods in a 200 ml beaker. Then, the mixture was heated in a water bath by gradually increasing the temperature from 50°C to 130°C. The mixture was heated at 50°C for the first hour, after which the temperature was increased to 100°C, after which the sample was heated for the next half an hour. Finally, the temperature was increased to 130°C, and the mixture was heated continuously until the temperature was reduced to half of the initial temperature.A similar procedure was repeated by replacing methanol with distilled water as a solvent.

c.Biosynthesis/green synthesis of silver nano particles using plant extracts:

Methanol extracts from the fruits of the plants were obtained, mixed with silver nitrate solution and

incubated overnight. Centrifugation was performed using a microcentrifuge at 5000 × g for 5 min.
The extract prepared by this method was then filtered through filter paper to remove coarse particles, and a brown-colored filtrate of approximately 24.5 ml was collected in a 50 ml beaker. Silver nitrate reagent was prepared by mixing 1.698 g of silver nitrate crystals in 100 ml of distilled water (100 mM). The Wrightia tinctoria extract (24.5 ml) was properly mixed with 100 ml of silver nitrate solution and stirred for a few minutes, after which the color change from clear brown to turbid dark brown was observed. The mixture was kept in the dark at room temperature for 24 h, the sample became turbid, and a precipitate was collected at the bottom of the beaker. The mixture was then centrifuged by using a microcentrifuge at 5000 × g for 5 minutes. The sample was added to 15 ml microcentrifuge tubes. The sample was placed into a microcentrifuge tube and centrifuged at 5000 × g for 5 minutes. The pellet obtained was collected by adding acetone to round bottom centrifuge tubes. The pellet was collected on a watch glass and kept overnight for evaporation. The crystals of the nanoparticles obtained weighed 1.5 g.

d.UV–visible spectroscopic analysis and anti microbial activity of green-synthesized silver nanoparticles

The resulting extracts were analyzed with a UV–visible spectrophotometer (Shimadzu-1780, Japan) by scanning the sample between 440 and 800 nm. The AgNPs were resuspended in distilled water, after which their antimicrobial capacities were studied. The broths of *E. coli* and *S. aureus* were prepared and incubated overnight at 37°C. Later, the confluent cultures of *E. coli* and *S. aureus* were spread on two agar plates carefully, and the wells were punctured by using sterilized gel puncture. The silver nanoparticle sample was poured into the wells created on both Petri plates. Three equidistant wells were used for puncture. The silver nitrate solution was added to the first well. In the second and third wells, the silver nanoparticle test sample and the plant extract were added, respectively. These Petri plates were again kept overnight in an incubator at 37°C. After this period, the Petri dishes were drawn and observed for the appearance of zones of inhibition. The efficacy of the AgNPs was calculated by measuring the zone of inhibition against *E. coli* and *S. aureus*.

Results and Discussion

The formation of silver nanoparticles was noted by detecting the change in color from light brown to dark brown with silver shade (Fig. 1). The presence of AgNPs was tested by using UV–visible spectroscopy at 400 to 800 nm. A small peak at 425 nm was observed, indicating the presence of AgNPs (Figure 2). The UV–visible spectrum of the biosynthesis of silver nanoparticles using *Wrightia tinctoria* showed a peak at 425 nm corresponding to the surface plasmon resonance of AgNPs for the tested fruit extracts of *Wrightia tinctoria*. Peak observations at 425 nm were also observed when the extracts of *T. harzianum* and *T. viride* were used for the green synthesis of AgNPs (Elamawi *et al.,* 2018). UV–visible absorption spectroscopy has been proven to be a sensitive method for the determination of silver nanoparticles because of surface plasmon excitation at this wavelength (Zaheer *et al.,* 2010). *Phyllanthus acidus* plant extracts are also known to reduce silver nitrate and act as capping agents for the synthesis of AgNPs. The formation of nanoparticles was confirmed by UV–vis spectrophotometry at 425 nm. This is justified by the formation of a surface plasmon resonance band at 425 nm (Soumya *et al.,* 2018). The synthesis of AgNPs by sodium borohydride and *Trigonella foenum-graecum* leaf extract as reducing and stabilizing agents has been confirmed. The formation of AgNPs at 425 nm after overnight incubation with silver nitrate and leaf extracts has also been shown (Kishore *et al.,* 2023). AgNPs have also been used in the identification of mercury ions in solution. The peak corresponding to the AgNPs used in this process was also 425 nm in length and was attributed to the AgNPs formed by green synthesis (Pomal *et al.,* 2021). To further confirm the formation of silver nanoparticles by using this method, the sample was subjected to characterization. This approach provides clear information about the size and shape of the nanoparticles.The zone inhibition method was used to study the antimicrobial activity of the strains (Banerjee *et al.* 2022). A good zone of inhibition of 2.6 ± 0.2 cm (Table 1 and Fig. 3) was observed for *E. coli,* and a zone of inhibition of 2.2 ± 0.1 cm (Table 2 and Fig. 3) was observed for *S. aureus*.

Figure 1: Silver nanoparticles synthesized from *Wrightia tinctoria* pod extracts

Table 1: Antimicrobial activity of silver nanoparticles formed using methanol as a solvent

Microorganism	Zone of inhibition (in cm) obtained with		
	Silver Nitrate	**W T extract (methanol)**	**Silver nanoparticles (5 mg SNP in 0.5 ml D. W.)**
***E. coli* (Gram Negative)**	1.2 ± 0.1	1.6 ± 0.1	2.0 ± 0.1
***S. aureus* (gram-positive)**	1.0 ± 0.1	1.2 ± 0.1	2.6± 0.2

Table 2: Antimicrobial activity of silver nanoparticles formed using distilled water as a solvent

Microorganism	Zone of inhibition (in cm) obtained with		
	Silver Nitrate	**WT extract (distilled water)**	**Silver nanoparticles (5 mg SNP in 0.5 ml D. W.)**
***E. coli* (Gram Negative)**	1.3 ± 0.1	0.8 ± 0.1	2.2 ± 0.1
***S. aureus* (gram-positive)**	1.1± 0.1	0.8 ± 0.1	1.8 ± 0.1

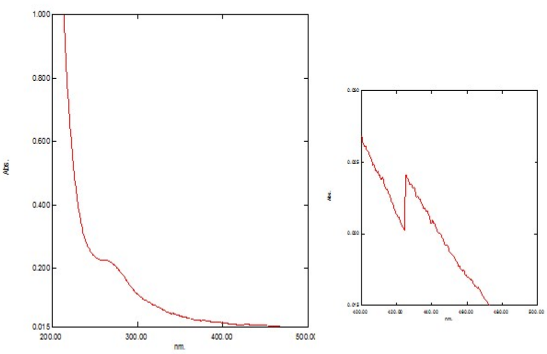

Figure 2: UV–visible spectrum showing the spectra of the extract at 400-800 nm

These findings suggest that the silver nanoparticles that formed antimicrobial activity against these two bacterial strains. AgNPs are known to have good inhibitory effects on gram-positive and gram-negative bacteria (Cavassin *et al.,* 2015). These antibacterial activities of the AgNPs can be attributed to the physicochemical properties of the

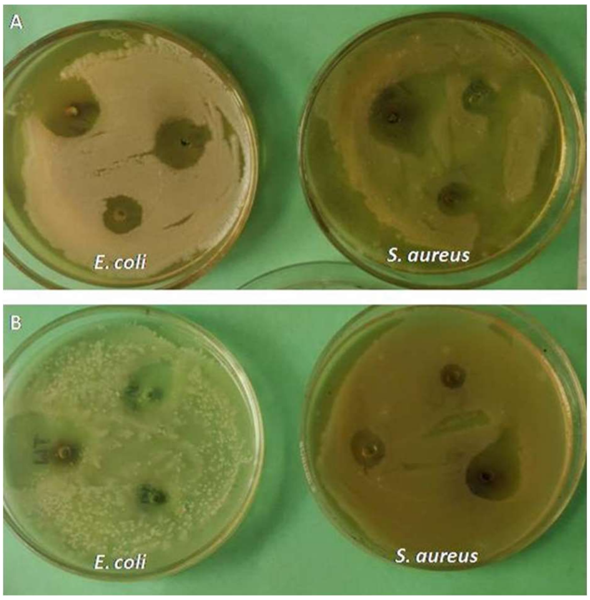

Figure 3: Antimicrobial activity of methanol (A) and distilled water (B) extracts

The shape, size, chemical and charge of AgNPs It can affect the interaction of particles with cell membranes and even pass through the intracellular membrane of bacteria. The continuous release of silver ions from AgNPs can cause the death of microbes (Bapat *et al.*, 2007). Silver ions can bind to the sulfur and phosphorous present in DNA. It can also cling to the cell wall and plasma membrane of microorganisms. Adherent ions are known to affect the permeability of the cell membrane and may generate reactive oxygen species, which can cause oxidative stress, leading to disruption of the cell (Khorrami *et al.,* 2018). Modulation of the signal transduction pathway leading to cell death is also known. AgNPs cause dephosphorylation of phosphotyrosines, which leads to cell signal transduction and cell death. Aerobic conditions are known to release Ag^+ from the surface of particles; Ag+ interacts with the cell membrane and cell wall components of bacteria and plays a crucial role in cell death (Bapat *et al.,* 2007). The antibacterial activities also depend on the sizes of the nanoparticles formed (Lu *et al.,* 2013). Among the sizes of nanoparticles formed (5 nm, 15 nm, and 55 nm), the 5 nm AgNPs had the greatest inhibitory effect on *E. coli*. This difference may be attributed to the oxidation of AgNPs in aqueous media when exposed to air. This reduces the antimicrobial activity potential of large AgNPs. In contrast, the larger nanoparticles showed greater antibacterial activity, which was explained by the greater surface area available for the larger nanoparticles (Agnihotri *et al.,* 2014). The positively charged AgNPs interact with the negatively charged bacterial cells to inhibit their growth. The antibacterial activities of AgNPs are also affected by the process of synthesis. The capping agent used for the synthesis may influence the effectiveness of the AgNPs as antimicrobial agents. The organic extracts used were described by Murei *et al.,* 2020, who confirmed the enhanced activities of the synthesized AgNPs. When conjugated with AgNPs and antibiotics such as ampicillin, the extracts of Pyrenacantha grandiflora showed a very low minimum inhibitory concentration compared to that of AgNPs alone. This was due to the synergistic effects of the antibiotic-coated AgNPs. Thus, *Wrightia tinctoria*-assisted AgNPs will be further coated with different agents, such as chitosan and antibiotics, to enhance their overall antibacterial capacities.

Conclusion

The objective of this study was to synthesize silver nanoparticles (AgNPs) from fruit extracts of *Wrightia tinctoria* and evaluate their antimicrobial capacities. The AgNPs were synthesized from methanolic and distilled water extracts, and the formation of AgNPs was confirmed by observing the change in color to dark brown with silver shade. The UV–visible spectrum showed a peak at 425 nm, which indicated the formation of AgNPs. The antimicrobial potential of the AgNPs was further tested against pathogenic strains of *E. coli* and *S. aureus*. The AgNPs synthesized from the extracts of *Wrightia tinctoria* showed a good zone of inhibition and hence promising antimicrobial potential against *E. coli* (2.2 ± 0.1 cm, gram-negative) and *S. aureus* (2.6 ± 0.2 cm, gram-positive).

Conflict of interest

The authors declare that they have no conflicts of interest.

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Evaluation of infiltration models in clay loam and laterite soils under field conditions

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ABSTRACT

The purpose of the investigation is to calculate soil infiltration rates with the help of infiltration models. The infiltration model helps to design and evaluate surface irrigation systems. The study calculated constant infiltration for two types of soils (clay loam soil and laterite soil) under field conditions (Unploughed and Ploughed). The double-ring infiltrometer has been implemented to experiment. The value of various constants of the models was calculated using the approach of averages counselled through a graphical technique. Fitting infiltration test data to prominent infiltration models such as Philip's, Horton's and Kostiakov's and The Nash- Sutcliffe efficiency (NSE), coefficient of determination (R^2) and root mean square error (RMSE) statistics are used to evaluate the effectiveness of the model. The results indicate that Philip's model is the most reliable, with R^2, NSE, and RMSE values ranging from 0.9044-0.9677, 0.294-0.957 and 1.2647-5.7129, respectively. Therefore, under identical circumstances and without any kind of infiltration information, the above model can be employed to artificially produce infiltration information.

Introduction

Rainwater catchment areas have shrunk as a result of fast development and settlement. Urban regions will experience increasing water runoff and flooding of the shrinking rainfall collection areas (Apollonio *et al.,* 2016). Water infiltration through soil occurs naturally. Significant contributions are made to the hydrological cycle by it. Infiltration is the process of movement of water from the ground surface into the earth's soil and increasing the overall amount of water present, which affects water partitioning and hydrological responses (Shakesby *et al.,* 2000; Walker *et al.,* 2007). Infiltration is crucial to hydrology because it limits the water reserves that can be used to fill groundwater wells and prevents water runoff and soil erosion (Angulo *et al.,* 2016). A Simple device known as a double-ring infiltrometer can be used to measure the infiltration of water into the soil Dagadu *et al.* (2012). Infiltration can be stated in two dimensions, the capability of infiltration and the rate is measured in mm/hr. The infiltration velocity depends on the type of soil and its characteristics. An individual type of soil's infiltration capacity is its maximum infiltration rate. Soil absorbs the water under specific conditions known as soil infiltration capacity (Dhalhar,1972). Eight different infiltration models were considered by (Mirzaee *et al.,*2014). These models were evaluated by least squares fitting to measure soil infiltration. For the NIT Kurukshetra campus, (Sihag *et al.,* 2017a) compared the infiltration models. In comparison to existing models, the novel model best matched the field infiltration data. The soil infiltration rate was predicted using various soft computing techniques (Singh *et al.,* 2017; Sihag *et al.,* 2017a, b; Sihag *et al.,* 2019). The current investigation's goal is to identify the model

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parameters and locate the most appropriate model for the soils of the research area specified below.

Material and Methods

Study Area

The current soil infiltration investigation is being performed at the Indira Gandhi Krishi Vishwavidyalaya in Raipur (C.G.) (Figure 1). It is in Chhattisgarh's East Central region at longitude $21^0$13'59"N, longitude $81^0$37'59"E and altitude 289.5 m above mean sea level. This region is sub-humid, with hot summers and cold winters. The rain is caused by the southwest monsoon. Based on an 80-year average, it receives 1312 mm of rain each year, with 85% of that falling between June and September. A few showers in the winter and a handful of showers in the summer are possible. The hottest month is May and the coldest month is December. While the winter minimum temperature dropped to 8°C, the weekly high temperature in the summer was 45.8°C. From June through October, relative humidity and wind speed are high, with a peak in June and July.

Measurement of infiltration rates

A Double ring infiltrometer (ASTM 2003) was used to determine the infiltration rates. The double-ring infiltrometer includes two rings. The outside ring is 30 cm in diameter and has a 60 cm outside diameter, driving the rings 8-9 cm into the ground. The hammer should strike the steel plate ring uniformly without disrupting the soil surface. The level of the water in both rings were same. Frequently measurements of the water depths in the infiltrometer were taken until a steady degree of infiltration was attained. The soil sample weighed between 100 and 150g as taken at a location near the experiment site to determine the amount of water present in the soil before estimation of infiltration rate.

Infiltration models and parameter

The three subsequent infiltration models were evaluated to decide which would most appropriately match the information on field infiltration rates.

Horton's model

The decline in infiltration capability over time was depicted in Horton's semi-empirical model as an exponential decay given by

$$I = f_c + (f_o - f_c)e^{-kt}$$

where,
I is Infiltration capacity or potential infiltration rate [cm/hr],
f_c is final constant infiltration rate [cm/hr],
f_o is initial infiltration capacity [cm/hr],
k is Horton's decay coefficient, which is dependent on soil characteristics and vegetation cover, and
t is the time after the start of infiltration (hr).

Kostiakov's model

The formula for cumulative infiltration expressed by Kostiakov's model is

$$F = at^b$$

where,
F is cumulative infiltration capacity (cm/hr)
t is time after infiltration starts, and
a and b are constants that depend on the soil and initial conditions.

Philip's model

The relationship shown below represents Philip's (1957) two-term model:

$$f_p = \frac{1}{2}st^{-\frac{1}{2}} + k$$

where,
f_p is infiltration capacity at any time step from the beginning
s is infiltration capacity at any time step from sorptivity of soil water,
k is the hydraulic conductivity of Darcy.

Estimation and inter-comparison of model parameter

Root mean square error (RMSE)

The root means the square error is abbreviated as RMSE. When using a statistical model to predict a numerical outcome, predicted values rarely match actual outcomes completely.

$$\text{RMSE} = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{n}(a_i - b_i)^2\right)}$$

where,
a is the calculated value of the infiltration rate
b is the value of the infiltration rate
N is the number of observations

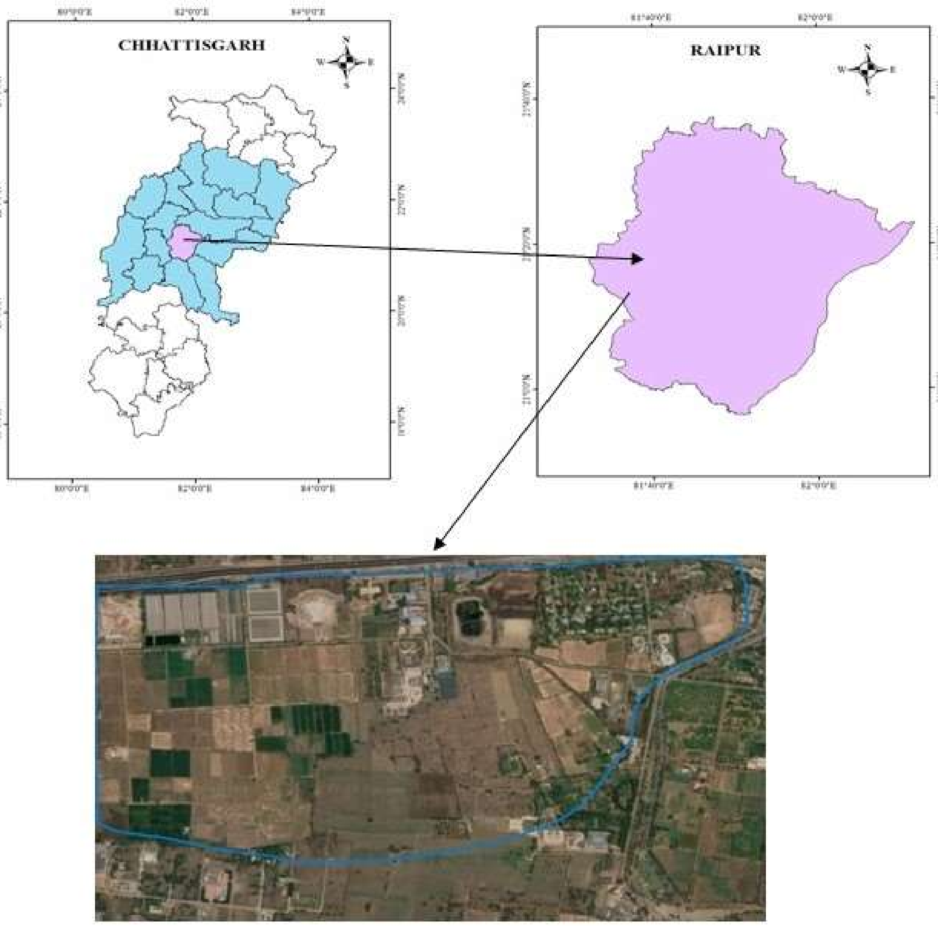

Figure 1: Location of the study area

Nash-Sutcliffe model efficiency coefficient

A normalized statistic called the Nash-Sutcliffe efficiency (NSE) measures how much residual variance there is in comparison to the variance of the measured data (Nash and Sutcliffe, 1970). A result of 80-90% shows moderately acceptable performance, a value of 80-90% indicates extremely good efficiency, while a value of less than 80% denotes an inadequate fit.

$$\text{Model efficiency} = \; 1.0 - \frac{\sum_{i=1}^{n}(x-y)^2}{\sum_{i=1}^{n}(x-\bar{x})^2}$$

Coefficient of determination (R^2)

A statistical model's capacity to explain and predict future events is determined and evaluated using the coefficient of determination, often known as R^2.

The mathematical formula for computing R^2 is

$$R^2 = \left(\frac{z\sum ab-(\sum a)(\sum b)}{\sqrt{z(\sum a^2)-\;(\sum a)^2}\;\sqrt{z(\sum b^2)-\;(\sum b)^2}}\right)^2$$

Results and Discussion

Infiltration rates of clay loam and laterite soils under field conditions

Table 1 presents the observed infiltration rates for different field conditions. From the table, for unploughed clay loam soil, the initial infiltration rate varies 18.0-0.9 cm/hr. Similarly, for ploughed clay loam soil, the initial infiltration rate varies from 16.8- 1.2 cm/hr. In the case of unploughed laterite soil, the initial infiltration rate varies from 22.8-3.5 cm/hr. For ploughed laterite soil, the initial infiltration rate was 24.0-3.7 cm/hr.According to the information provided in Table 1, it can be observed that over time, the infiltration rate generally decreases with some rapid fluctuations. These fluctuations are due to factors like the presence of macro-pores such as rodent holes, earthworm channels, or root pathways in the soil, which facilitate increased water flow. The sudden increase in infiltration rates can also be caused by the release of trapped air from soil aggregates. This is supported by the observation of rodent holes and air bubbles during the infiltration tests. On the other hand, the sudden decrease in infiltration rates is attributed to the perching phenomenon, where water accumulates at different depths. It is important to note that these patterns are observed in both soil conditions (Garg *et al.,* 2005). The soil conditions affect the infiltration rate. The infiltration rate is higher in a ploughed condition of soils compared to unploughed conditions (Dagadu *et al.,* 2012). These fluctuations in the infiltration rate were due to soil profile (Mahapatra *et al.,* 2020). Ploughed soil can increase infiltration rates due to improved soil structure, increased porosity, reduced surface crusting and enhanced water pathways. However, the effects can vary depending on factors like soil type and ploughing technique. Proper ploughing practices are essential to optimize infiltration rates

Table 1: Infiltration rate (cm/hr) of soil under different field conditions

Time (min)	Infiltration rate (cm/hr)			
	Clay loam soil		Laterite soil	
	Unploughed	Ploughed	Unploughed	Ploughed
5	18	16.8	22.8	24.0
10	15.6	15.6	19.2	20.4
20	7.8	6	8.4	8.4
30	7.2	4.8	7.2	7.2
45	3.2	3.6	5.2	5.2
60	2.8	3.6	4.8	5.6
80	1.2	1.8	3.9	3.8
100	0.9	1.2	3.5	3.7
120	0.9	1.2	3.5	3.7

Computation of the model constants

Table 2 displays the values of several infiltration model parameters for various soil conditions for Horton's, Philip's and Kostiakov's infiltration models applied to clay loam soil under field conditions. For Horton's model, the empirical constant 'k' has values of 2.53 and 2.19. In Kostiakov's infiltration model, the empirical constants 'a' have values of 6.40 and 5.99, while 'b' has values of 0.50 and 0.51, respectively. In Philip's model, the constants 's' has values of 13.73 and 12.57 and 'k' has values of -3.95 and -3.41. Infiltration models applied to laterite soil under field conditions. For Kostiakov's infiltration model, the empirical constants 'a' have estimated values of 8.58 and 8.85, while 'b' has values of 0.56 and 0.55. In Horton's model, the empirical constant 'k' has estimated values of 2.98 and 2.85., respectively. In Philip's model, the constants 's' has estimated values of 15.36 and 16.29, and 'k' has values of -2.85 and -3.21.

Observed infiltration data was utilized to study and analyze these models. The infiltration equations were evaluated using experimental data from the study area, to determine the numerical values for the parameters in the models. Based on the findings, it was discovered that different soil types and soils have different parameter values for infiltration models (Dagadu *et al.,* 2012). When fitting the Philip Two-Term model to infiltration data taken from real field conditions, several researchers have also reported negative values of K in the literature (e.g., Shukla *et al.,* 2003; Machiwal *et al.,* 2006). The negative values of K found in this study are likely caused by macropores and relatively impeded (low-permeability) layers at various depths. The input variables for various infiltration models were established. All the observation points infiltration equations for various types of soils and field circumstances were developed using these model constants.

Table 2: The values of various infiltration model parameters for various soil types under various field circumstances

Soil types	Horton's model	Kostiakov's model		Philip's model	
	k	a	b	s	k
Clay loam soil (Unploughed)	2.53	6.40	0.50	13.73	-3.95
Clay loam soil (Ploughed)	2.19	5.99	0.51	12.57	-3.41
Laterite soil (Unploughed)	2.98	8.58	0.56	15.36	-2.85
Laterite soil (Ploughed)	2.85	8.85	0.55	16.29	-3.21

Comparison of observed and estimated infiltration rates for clay loam soil

Table 3 and Figure 2 show the comparison of observed and model-estimated infiltration rates under unploughed conditions in Clay loam soil. The initial infiltration rate predicted by Philip's model was 19.84 cm/hr, which was near to observed infiltration rate 18.00 cm/hr. Similarly, it was predicted by Horton's model as 14.74 cm/hr and the Kostiakov's model as 22.05 cm/hr differentiating highly from the observed value. The infiltration rates were decreased from 18.00 to 0.90 in observed value, in the case of Philip's 19.84 to 0.91 cm/hr, 22.05 to 4.53 cm/hr for Kostiakov's and 14.74 to 0.90 cm/hr for Horton's model respectively. The computed values of infiltration rates by different models for ploughed Clay loam soil are presented in Table 4 and Figure 3. The initial infiltration rate predicted by Philip's model is 18.37 cm/h, which was close to the observed infiltration rate 16.80 cm/hr. Similarly, this was predicted by Horton's model as 14.20 cm/hr and the Kostiakov's model as 21.27 cm/hr both, deviated significantly from the observed value. The infiltration rates were decreased from 16.80 to 1.20 in observed value, 18.37 to 1.04 cm/hr in the case of Philip's, 21.27 to 4.21 cm/h for Kostiakov's and 14.20 to 1.20 cm/hr for Horton's model respectively. In this study, derived infiltration rates of clay loam soil were compared with three different models: Kostiakov's, Horton's and Philip's models. Observed and estimated infiltration rates were examined under field conditions (ploughed & unploughed). Upon analyzing the data in the results, found that Kostiakov's model exhibited the largest variation compared to the measured data at every sampling point. This indicates that Kostiakov's model consistently overestimated the infiltration rates. The poor performance of Kostiakov's model could be attributed to its limitations in accurately representing the behaviours of infiltration in clay loam soil. Horton's model performed poorly but less than Kostiakov's model, possibly due to inconsistent physical interpretation of parameters and errors in estimating initial and steady-state infiltration rates, leading to an inadequate fit to the measured data. Philip's model outperformed the others, fitting the measured data well and showing suitability for estimating infiltration rates in clay loam soil.

Table 3: Comparison of observed and estimated infiltration rates for unploughed Clay loam soil

Infiltration rate (cm/hr)				
Time(min)	Observed infiltration	Horton's model	Kostiakov's model	Philip's model
5	18.00	14.74	22.05	19.84
10	15.60	10.54	15.61	12.87
20	7.80	3.86	11.06	7.95
30	7.20	2.67	9.03	5.76
45	3.20	1.24	7.38	3.98
60	2.80	1.05	6.40	2.92
80	1.20	0.91	5.54	2.00
100	0.90	0.90	4.96	1.37
120	0.90	0.90	4.53	0.91

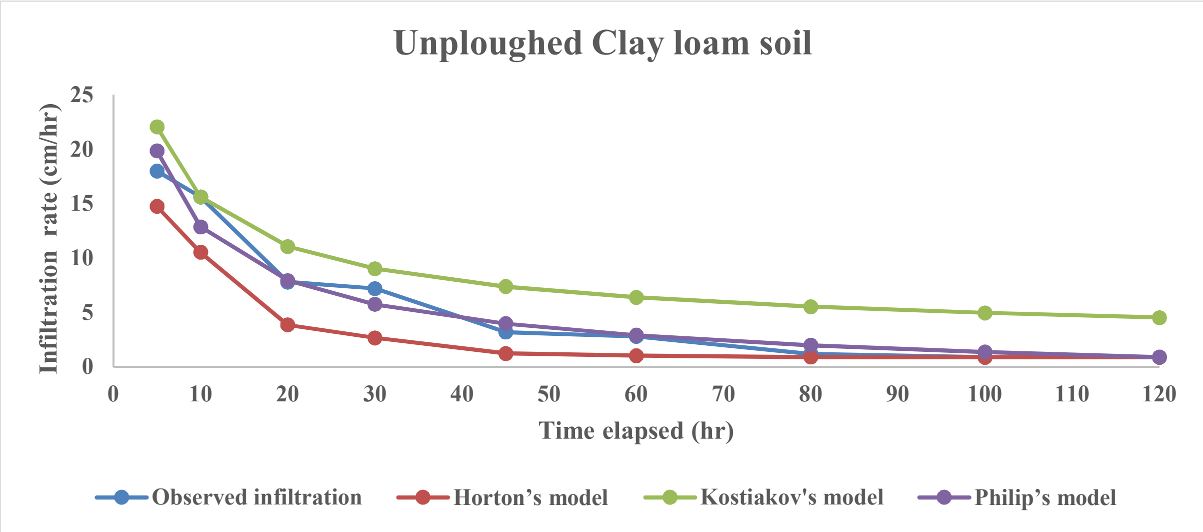

Figure 2: Observed and estimated infiltration rates for unploughed Clay loam soil

Table 4: Comparison of observed and estimated infiltration rates for ploughed Clay loam soil

	Infiltration rate (cm/hr)			
Time(min)	**Observed infiltration**	**Horton's model**	**Kostiakov's model**	**Philip's model**
5	16.80	14.20	21.27	18.37
10	15.60	11.19	14.93	11.99
20	6.00	3.51	10.49	7.48
30	4.80	2.40	8.53	5.48
45	3.60	1.66	6.93	3.85
60	3.60	1.47	5.99	2.88
80	1.80	1.23	5.17	2.04
100	1.20	1.20	4.61	1.46
120	1.20	1.20	4.21	1.04

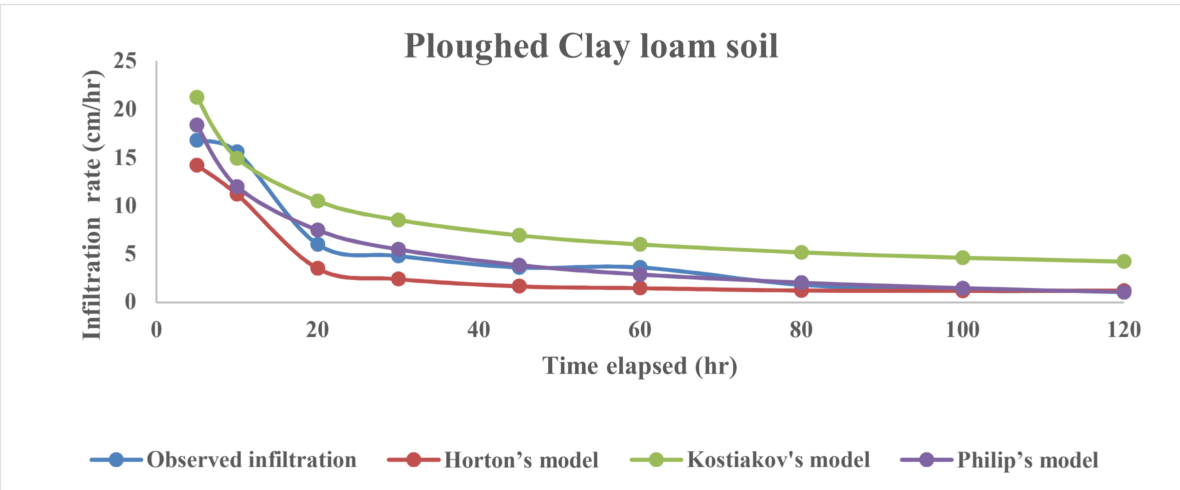

Figure 3: Observed and estimated infiltration rates for ploughed Clay loam soil

This result collaborates with the findings (Thomas et *al.,* 2020; Saadi *et al.,* 1985) who used the six-infiltration model in textured soil and found that Philip's model gave a good representation of the infiltration model while Kostiakov's, modified Kostiakov's, Green Ampt and Holtan Overton performed in that order respectively as adduced by Igbadun *et al.,* (2016). However, the most successful prediction of accurately matched test data was an estimation of the infiltration rate made by Philip's model. Additionally, its performance in the absence of field data suggests its potential for practical applications without direct measurements.

Comparison of observed and estimated infiltration rates for laterite soil

Table 5 and Figure 4 show the comparison of observed and model-estimated infiltration rates under unploughed conditions in Laterite soil. The initial infiltration rate predicted by Philip's model was 23.75 cm/hr, which was near to observed infiltration rate 22.80 cm/h. Similarly, it was predicted by Horton's model as 18.56 cm/hr and the Kostiakov's model as 34.17 cm/hr differentiating highly from the observed value. The infiltration rates decreased from 22.80 to 3.51 in observed value, 23.75 to 2.58 cm/hr in the case of Philip's, 34.17 to 5.84 cm/hr for Kostiakov's and 18.56 to 3.51 cm/hr for Horton's model respectively. The computed values of infiltration rates by different models for ploughed Laterite soil are presented in Table 6 and Figure 5. The initial infiltration rate predicted by Philip's model is 25.00 cm/hr, which was close to the observed infiltration rate 24.00 cm/hr.

Table 5: Comparison of observed and estimated infiltration rates for unploughed laterite soil

	Infiltration rate (cm/hr)			
Time(min)	**Observed infiltration**	**Horton's model**	**Kostiakov's model**	**Philip's model**
5	22.8	18.56	34.17	23.75
10	19.2	13.06	23.24	15.96
20	8.4	5.32	15.81	10.45
30	7.2	4.34	12.62	8.01
45	5.2	3.69	10.07	6.02
60	4.8	3.58	8.58	4.83
80	3.9	3.52	7.31	3.80
100	3.51	3.51	6.46	3.10
120	3.51	3.51	5.84	2.58

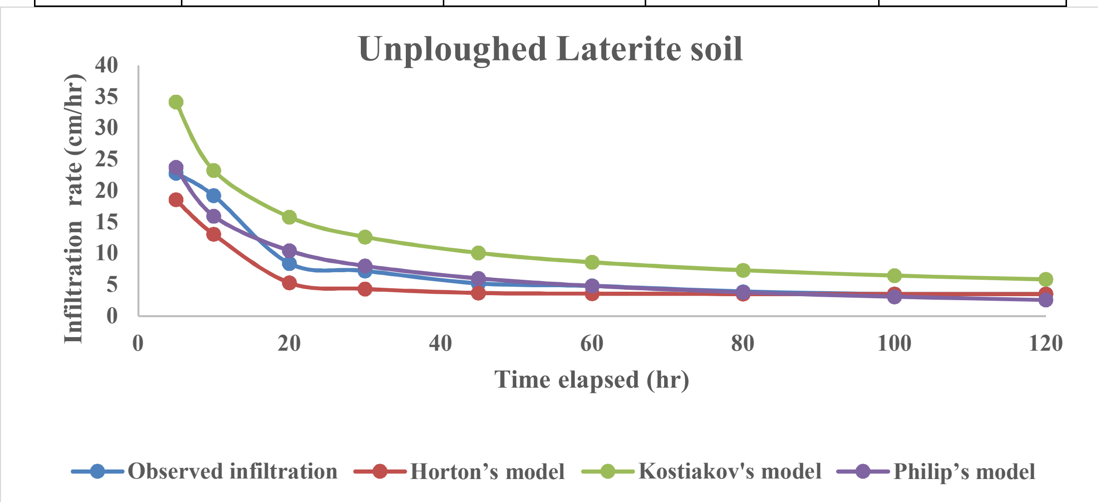

Figure 4: Observed and estimated infiltration rates for unploughed Laterite soil

Table 6: Comparison of observed and estimated infiltration rates for ploughed laterite soil

Infiltration rate (cm/hr)				
Time(min)	**Observed infiltration**	**Horton's model**	**Kostiakov's model**	**Philip's model**
5	24	19.71	34.47	25.00
10	20.4	14.09	23.59	16.74
20	8.4	5.53	16.15	10.89
30	7.2	4.56	12.93	8.31
45	5.2	3.89	10.36	6.19
60	5.6	3.83	8.85	4.93
80	3.3	3.71	7.56	3.84
100	3.72	3.72	6.69	3.10
120	3.72	3.72	6.06	2.55

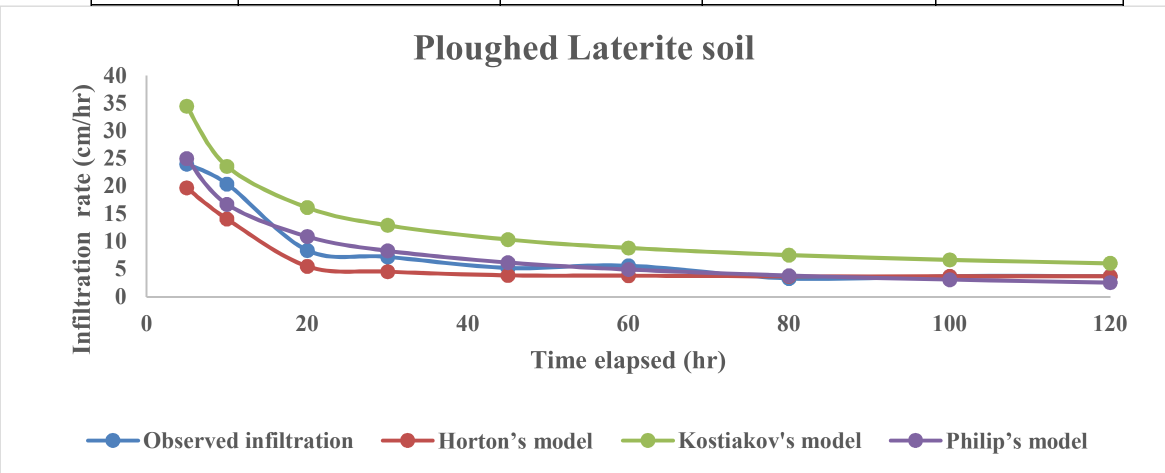

Figure 5: Observed and estimated infiltration rates for ploughed laterite soil

This was estimated by Horton's model as 19.71 cm/hr and Kostiakov's model as 34.47 cm/hr, both deviated significantly from the observed value. The infiltration rates were decreased from 24.00 to 3.72 in observed value, 25.00 to 2.55 cm/hr in the case of Philip's, 34.47 to 6.06 cm/hr for Kostiakov's and 19.71 to 3.72 cm/hr for Horton's model respectively. The same models (Kostiakov's, Horton's and Philip's) were also used for laterite soil. These models were tested by comparing their results with observed and estimated levels of infiltration rate in field conditions, particularly in the case of ploughed and unploughed. The models of Kostiakov's have shown the highest variation, according to these results. This suggests that the model consistently overestimated the measured data at each sample location. This overestimation shows that the model predictions are not compatible with the observed field measurements. Thus, the model Kostiakov's did not provide an accurate representation of infiltration rates in the laterite soil studied. Horton's model did not perform as poorly as Kostiakov's, perhaps due to a lack of physical interpretation of the parameters and incorrect estimation of initial and continuous state infiltration rates which resulted in an inadequate fit with measured data. Philip's model performed well. This result agrees with research (Thomas *et al.,* 2020; Saadi *et al.,* 1985) that used six infiltration models in textured soil and discovered that Philip's model provided a good representation of the infiltration model while Kostiakov's, modified Kostiakov's, Green Ampt and Holtan Overton performed in that order, as suggested by Igbadun *et al.,* (2016). incorporating the measured data and indicating suitability for predicting infiltration of Laterite soils. In addition, its potential for practical use without direct measurements is shown by its ability to work in the absence of field data. However, the most successful prediction of accurately matched test data was an estimation of the infiltration rate made by Philip's model.

Estimation and inter-comparison of model parameter

The statistics shown in Table 7 clearly shows that all infiltration models accurately estimate the infiltration rate. The model that provided the best fit was selected based on the criteria of minimizing RMSE and maximizing NSE and R^2. The results of this evaluation are summarized in Table 7. Table 7 shows that all the models perform effectively with very low errors (RMSE) ranging from 1.2647 to 5.7129, extremely high values of R^2 (0.9044-0.9677), and moderate to very good values of model efficiency (NSE: 0.294-0.957), all of which show that these infiltration models are excellent at predicting infiltration rates. In terms of the RMSE criteria, Horton's (mean RMSE=2.5375) and Kostiakov's (mean RMSE=4.5147) models come in second and third, respectively, with Philip's model having the lowest mean RMSE (1.3758). According to the RMSE values, the Philip Two-Term performs approximately equally in estimating infiltration. Philip's model has the highest mean NSE value of 0.948, according to the measured NSE values (Table 7). From Table 7, it is evident that Horton's models' efficacy is excellent, with an NSE value of 0.824, respectively. Kostiakov's models, on the other hand, perform poorly with an NSE value of 0.40, respectively. Despite having very high R^2 values (>0.94) in a variety of situations, all the models had comparable rankings to model efficiency (NSE) in terms of R^2 values.

Table 7: Inter-comparison parameter of infiltration models

Soil conditions	Horton's model	Kostiakov's model	Philip's model
Root mean square error (RMSE)			
Clay loam soil (Unploughed)	2.9660	3.4850	1.2647
Clay loam soil (Ploughed)	2.2793	3.3879	1.4484
Laterite soil (Unploughed)	2.9319	5.7129	1.4133
Laterite soil (Ploughed)	1.9729	5.4731	1.3767
Average	**2.5375**	**4.5147**	**1.3758**
Nash-Sutcliffe efficiency (NSE)			
Clay loam soil (Unploughed)	0.836	0.638	0.934
Clay loam soil (Ploughed)	0.814	0.294	0.957
Laterite soil (Unploughed)	0.814	0.294	0.957
Laterite soil (Ploughed)	0.834	0.403	0.946
Average	**0.824**	**0.407**	**0.948**
Coefficient of determination (R^2)			
Clay loam soil (Unploughed)	0.9044	0.9624	0.9624
Clay loam soil (Ploughed)	0.9435	0.9476	0.9491
Laterite soil (Unploughed)	0.9666	0.9569	0.9568
Laterite soil (Ploughed)	0.9677	0.9470	0.9464
Average	**0.9456**	**0.9535**	**0.9537**

These infiltration models were chosen based on how well they performed in most field situations as measured by R^2, RMSE, and NSE. Based on the analysis of parameters RMSE, NSE and R^2, it can be concluded that Philip's model demonstrated a strong agreement with the measured data, indicating superior performance compared to Horton's and Kostiakov's models. This result corroborates the findings of Thomas *et al.* (2020), who evaluated four infiltration equations on silt and sandy soils. They concluded that Philip's model provided a highly accurate representation of infiltration, followed by Kostiakov's, Green Ampt, and Horton's models followed in that respective order, as indicated by Igbadun *et al.* (2016). Similarly, Oku & Aiyelari (2011) predicted cumulative infiltration in Inceptisols within humid forest zones and found that Philip's model outperformed Kostiakov's model. These studies imply that certain infiltration models are more suitable for specific site conditions (Machiwal *et al.* 2006), this implies that not all infiltration models can be universally applied to all types of soils. Different models may have varying levels of applicability depending on the soil characteristics and conditions of a particular site.

Conclusion

The study shows that the infiltration rate is influenced by the soil properties. Infiltration rates started high and fell over time until they reached a constant level, according to graphs showing infiltration rates vs time. One of the main fields of study in hydrology is infiltration, a crucial part of the hydrological cycle. Planning and developing water resource systems and comprehending the rainfall-runoff process depend on data on infiltration rates for different soil types. The infiltration rate vs time graphs for field data and model data do not match exactly, but Philip's model is substantially closer to the observed field data. This is discovered while comparing infiltration models to field data. Based on the mean values of RMSE, NSE, and R^2, Philip's model had the lowest RMSE and highest NSE and R^2 values, indicating that it accurately represented the infiltration rate. Thus, it can be used to create infiltration data artificially in the absence of infiltration data that have been detected. So, in any further research work prefer Philip's model

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Epidemiological study of Alternaria blight of cabbage in Jorhat district of Assam, India

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ABSTRACT

The field experiment conducted during the period of 2021-2022 at the Department of Horticulture, AAU, Jorhat, has shown that the timing of transplantation significantly impacts the severity of Alternaria blight in cabbage. The study revealed that the timing of transplanting significantly affects disease severity. The crop transplanted in the month of December exhibited the highest disease intensity (maximum and minimum temperatures 24.76°C and 10.58°C, morning and evening relative humidity 98.41% and 57.13% respectively). The disease intensity was the lowest in October transplanted crops (maximum and minimum temperature 26.94°C and 12.22°C, relative humidity morning 96.12% and evening 55.13% respectively). The December transplanted crop had the highest AUDPC at 1317.75, followed by the February transplanted crop at 1037.85. With respect to the correlation matrix, rainfall and relative humidity showed a strong positive correlation with PDI whereas BSSH and temperature (maximum and minimum) all revealed a negative correlation. The multiple regression analysis revealed a substantial relation between disease intensity and meteorological conditions. The multiple regression equation indicated that the overall influence of all environmental parameters, namely (maximum and minimum) temperature, (morning and evening) relative humidity, rainfall, and BSSH on disease development ranged from 63.19% to 82.94%.

Introduction

The most common winter vegetable in India is cabbage (*Brassica oleracea* L var. *capitata*), which is profitable for farmers and belongs to the family Brassicaceae. Cabbage is most likely a native of Western Europe and the Northern Mediterranean region (Thompson and Kelly, 1957). This introduced vegetable crop has now thrived and spread throughout the Indian subcontinent. China is the largest producer of cabbage followed by India (Chadha, 2003). West Bengal, Orissa, Gujarat, MP, Bihar, and Assam are India's top cabbage-producing states. As per the data of Horticultural Statistics at a Glance (2018), Assam produced 640.13 thousand MT of cabbage in an area of 33.24 thousand ha during the year 2017-18 with a productivity of 19.26 MT/ha. The productivity was much less as compared to the country as a whole (22.7 MT/ha). The most prevalent and harmful disease of cabbage and Brassicas in the world are thought to be Alternaria leaf blight which is caused by *Alternaria brassicicola* (Meah *et al.,* 2002). The Pathogen infects the cabbage plant during the entire development stage of the crop (Valkonen and Koponen, 1990). Small brown patches on the leaves are the first signs, which progressively grow into larger lesions with concentric circles where spores

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are formed. The disease initiates in the lower part of leaves and gradually progresses to the upper shoots, leaves, petioles, pods, and heads. On severely infected plants, defoliation of the outer leaves may occur. Aside from yield, susceptible varieties may experience a significant quality loss due to this disease. The pathogen needs free water for spore germination and the ideal temperature for spore germination, mycelial development and plant infection is 20°C to 30°C (Humpherson and Phelps, 1989), heavy dew and regular rains promote conidia formation (Nowicki *et al.,* 2012). Alternaria leaf blight development is primarily governed by environmental factors. The climatic factors, including temperature (maximum and minimum), humidity, rainfall and BSSH are crucial in the development of disease (Selvamani, 2014). As a result, it is important to examine critically how various epidemiological variables contribute to the emergence of crucifer disease in order to create efficient management strategies (Kumar and Kolte, 2001). Moreover, a mathematical model for predicting the correlation between climatic variables and disease intensity is urgently needed for successful management.

Material and Methods

The Randomised Block Design (RBD) with four replications for each treatment was used for the experiment. The entire experiment was conducted in the experimental field of the Department of Horticulture AAU, Jorhat. Twenty plots with the dimension 2.4 X 2.4 m^2 were prepared for the experiment for the following treatment combinations consisting of five dates of transplanting (DOT)- T1: 30th October, T2: 30th November, T3: 30th December, T4: 30th January, T5: 28th February. Throughout the experiment, the cabbage variety "Pride of India" was used. One month old seedlings were transplanted into each plot at a distance of 60 X 45 cm^2. The other cultivation techniques were used in accordance with the package of practice prepared by AAU, Jorhat, except for the management of the disease. Observations of Percent Disease Intensity (PDI) were recorded every fortnight in each treatment on 10 randomly selected plants from each plot (Selvamani *et al.,* 2014). The disease rating scale of 0-5 (Conn *et al.,* 1990) was used to record the data of disease severity, where 0 indicates no symptoms on the leaf; 1 indicates that less than 5% of the leaf surface is affected; 2 indicates circular grey spots, with concentric rings covering 6-10% of the leaf surface; 3 indicates enlarged lesions, grey circular spots with a black border and concentric rings covering 11-25% of the leaf surface; 4 indicates spots covering 26-50% of the leaf surface; and 5 indicates lesions with concentric rings and a black border which covers 50% or more of the leaf surface. The following method for determining disease intensity (McKinney, 1923) was used to compute the per cent disease intensity:

$$\textit{Disease intensity}\ (\%) = \frac{\text{Sum of all the disease ratings}}{\text{Total number of ratings x Maximum disease grade}}\ X\ 100$$

The Area Under Disease Progress Curve (AUDPC) was calculated using the method proposed by Campbell and Madden (1990).

$$AUDPC = \sum_{i=1}^{n-1} \frac{\mathrm{y_i} + \mathrm{y_{i+1}}}{2} X(\,t_{i+1} - t_i)$$

Where, y_i= Cumulative intensity of disease at i^{th}observation; ti= Time (number of days after transplanting) at i^{th}observations
n = Total no of observations.

The weather parameters, maximum and minimum temperature, rainfall, morning and evening relative humidity, and BSSH were recorded during the crop-growing period of October 2021 to May 2022 in order to assess the effects of various weather factors on the development of the disease. To determine the correlation between disease intensity and meteorological conditions, multiple regression analysis and correlation with disease intensity were also conducted. The forecasting formula shown below was employed (Gupta *et al.,* 2003; Jha *et al.,* 2013).

$$\mathrm{Y = a + b1A1 + b2A2 + b3A3 + b4A4 + b5A5 + b6A6}$$

Where, Y= Disease severity (predicted); a= Intercept; b1 to b6= Partial regression coefficients; A1: Temperature (maximum) (°C); A2: Temperature (minimum) (°C); A3: Relative humidity (morning) (%); A4: Relative humidity (evening) (%); A5: Total rainfall (mm) and A6: BSSH (Sunshine/day)

Results and Discussion

Knowledge of disease intensity concerning meteorological parameters can help ensure successful and environmentally friendly control of cabbage leaf blight. This will allow them to forecast the emergence of the disease and assist producers in taking appropriate management action. The severity of Alternaria leaf blight of cabbage is heavily influenced by the weather (Table 1 and Fig 1). The crops transplanted in the month of October showed the lowest per cent disease intensity (PDI= 4.42, 8.96, 9.53, 10.5 and 12.21 in 1st, 2nd, 3rd, 4th and 5th fortnight respectively), whereas crop transplanted in the month of December showed the per cent disease intensity (PDI= 14.47, 16.73, 20.42, 22.44 and 27.33 in 1st, 2nd, 3rd, 4th and 5th fortnight respectively) in the field experiment. Notably, each fortnight of 30th October transplanted crops exhibited significantly lower disease intensity compared to the significantly higher disease intensity observed in cabbage transplanted on 30th December. During the month of October the average maximum temperature, minimum temperature, relative humidity (morning), relative humidity (evening), rainfall and the BSSH were 26.94°C, 12.22°C, 96.12%, 55.13%, 0.34 mm, 7.18 h respectively (Fig. 2). The meteorological parameters viz. the average maximum temperature, minimum temperature, relative humidity (morning), relative humidity (evening), rainfall and the BSSH were respectively during the month of December 24.76 °C, 10.58°C, 98.41%, 57.13%, 0.90 mm, and 5.8 h respectively. The combination of fairly low temperatures and moist, humid weather may be responsible for the development of Alternaria blight disease. Bart and Thomma, (2003) also reported the temperature between 20 to 27°C and relative humidity of 95-100% as essential parameters for developing the disease on crucifers caused by *Alternaria brassicicola*. Humpherson and Phelps (1989) similarly found that *Alternaria brassicicola* is responsible for Alternaria disease on cabbage. They observed that the severity of the disease increased when the pathogen generated spores in 12 to 14 hours, under optimal temperatures ranging from 18 to 24°C and 20 to 30°C. The pathogen requires free water for spore germination and the ideal temperature for spore germination, mycelial development, and plant infection. The severity of Alternaria blight rises with an average temperature between 13.5°C and 19.3°C and the disease intensity gradually increases with the days after sowing. This occurrence might be attributed to the delayed sowing resulting in the plant's vulnerable growth stage coinciding with the warm temperatures and high humidity as mentioned by Mahapatra *et al*. (2022). The plots transplanted in December had the highest average AUDPC (1317.75), followed by those transplanted in February (1037.85), January (983.25), November (728.4), and October (592.73) (Fig 3). The outcomes of this experiment were consistent with those of Hossain and Mian (2005) they observed that the severity of *Alternaria* blight increased with delay in planting. The crops planted in October had the lowest severity and those planted in December had the greatest. The seed yield per hectare was higher in October and November plantings than in December. According to Fagodiya *et al.* (2022), the severity of Alternaria leaf spot in soybean crops, as measured by the variance of AUDPC, is influenced by both the month of sowing and weather conditions. They found that various weather parameters and sowing dates play a significant role in the onset of the disease, affecting the infection process and pathogen spread. Yield and other growth parameters (numbers of loose leaves /plant, plant spread, diameter of head and head weight/plant) were found to be significantly better in early transplanted crops except for the plant height which was found non-significant in entire treatments (Table-2). The early transplanted crop on October 2021, had the highest yield (16.25 kg per plot or 28.21 t/ha), whereas the late transplanted crop on February 2022, had the lowest yield (10.52 kg per plot) (Table 2). Differences in the intensity of Alternaria blight may be one of the factors behind the different performance of transplanting dates on yield and other yield parameters. Similar findings were also reported by Lavanya *et al.* (2015) on cabbage they found that early transplanted crops gave better results in the case of yield and other attributes as compared to the latter transplanted crops. The figures followed by the same letters in the superscript are not significantly different at 5% significance level. The correlation coefficient depicted in Table 3 showed that there was a significant negative correlation with the maximum temperature on all the treatments except in the crop transplanted on 28th February (-0.835) where a non-significant negative correlation was recorded.

Table 1: Effect of date of transplanting on per cent disease intensity (PDI) of Alternaria blight under field conditions

Date of transplanting	PDI				
	1st fortnight	2nd fortnight	3rd fortnight	4th fortnight	5th fortnight
30th October	4.42^{d}	8.96^{c}	9.53^{d}	10.50^{c}	12.21^{d}
30th November	8.80^{c}	9.51^{c}	10.31^{d}	11.29^{c}	17.54^{c}
30th December	14.77^{a}	16.73^{a}	20.42^{a}	22.44^{a}	27.33^{a}
30th January	10.62^{b}	12.55^{b}	14.24^{c}	18.08^{b}	20.52^{b}
28th February	8.34^{c}	14.28^{b}	17.31^{b}	18.92^{b}	20.98^{b}
SEd (±)	**0.61**	**1.08**	**1.28**	**0.91**	**1.28**
CD at 0.05	**1.33**	**2.36**	**2.80**	**1.98**	**2.79**

The figures followed by the same letters in the superscript are not significantly different at 5% significance level

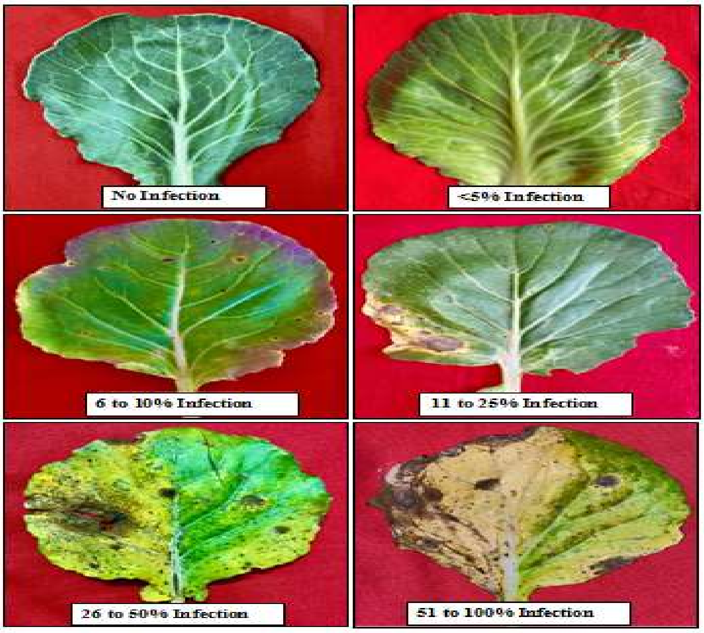

Figure 1: Scoring of disease infected leaves from 0-5 scale according to Conn *et al*. (1990)

Table 2: Effect of different transplanting dates on growth parameters and yield of Cabbage

Treatments	Plant height (cm) at 75 DAT	No. of lose leaves /plant	Plant spread (cm)	Dia. of head (cm)	Head weight (kg)/plant	Yield/plot (kg)	Yield (t/ha)
30th Oct, 2021	29.5	14.54^{a}	54.34^{a}	18.26^{a}	0.818^{a}	16.25^{a}	28.21^{a}
30th Nov, 2021	29.4	13.47^{b}	53.33^{a}	18.09^{a}	0.807^{a}	16.03^{a}	27.84^{a}
30th Dec, 2021	28.5	13.38^{bc}	51.73^{a}	16.16^{b}	0.741^{a}	14.62^{ab}	25.37^{ab}
30th Jan, 2022	28.4	12.57^{cd}	47.52^{b}	13.54^{c}	0.581^{b}	11.95^{bc}	20.79^{bc}
28th Feb, 2020	27.3	11.75^{d}	45.64^{b}	13.08^{c}	0.477^{c}	10.52^{c}	18.27^{c}
SEd (±)	**NS**	**0.39**	**1.89**	**0.76**	**0.045**	**1.54**	**2.23**
CD at 0.05	**NS**	**0.86**	**4.11**	**1.66**	**0.098**	**3.36**	**4.86**

Table 3: Correlation matrix between weather parameters with PDI on different transplanting dates

Date of transplanting	Correlation coefficient (r)					
	Weather factors					
	A_1	A_2	A_3	A_4	A_5	A_6
30th Oct, 2021	-0.970$^{(**)}$	-0.923$^{(*)}$	0.973$^{(**)}$	-0.987$^{(**)}$	0.929$^{(*)}$	-0.795
30th Nov, 2021	-0.971$^{(**)}$	-0.862	0.944$^{(*)}$	0.965$^{(**)}$	0.990$^{(**)}$	-0.917$^{(*)}$
30th Dec, 2021	-0.967$^{(**)}$	-0.867	0.928$^{(*)}$	0.954$^{(*)}$	0.862	-0.955$^{(*)}$
30th Jan, 2022	-0.979$^{(**)}$	-0.929$^{(*)}$	0.932$^{(*)}$	0.970$^{(**)}$	0.906$^{(*)}$	-0.930$^{(*)}$
28th Feb, 2022	-0.835	-0.859	0.930$^{(*)}$	0.932$^{(*)}$	0.921$^{(*)}$	-0.948$^{(*)}$

(*) correlation is significant at 0.05 level. (**) correlation is significant at 0.01 level.

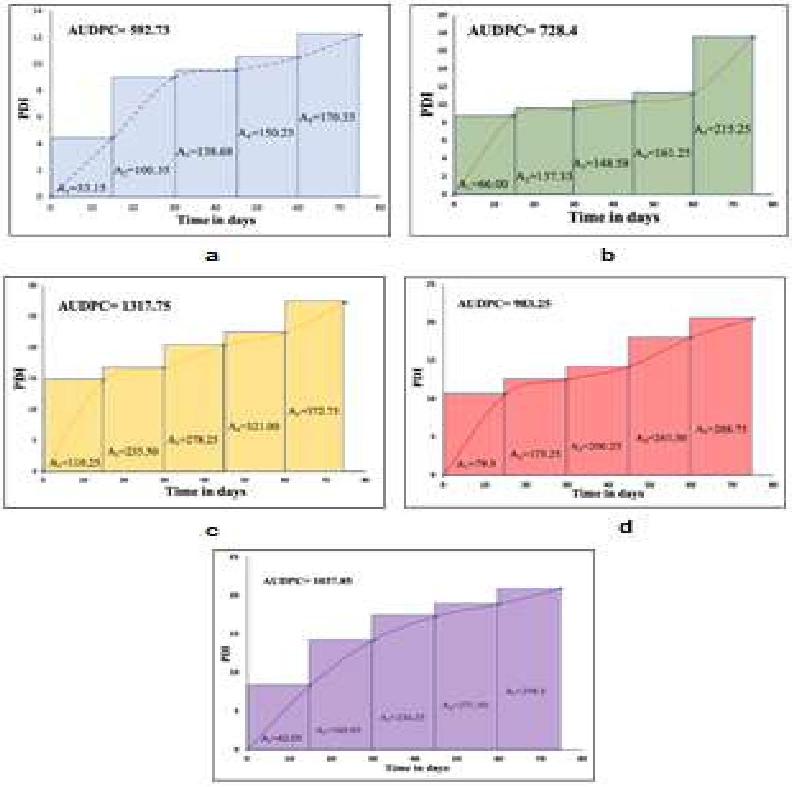

Figure 2: Effects of different dates of transplanting on AUDPC in relation to the Per cent disease intensity (PDI) of leaf spot of cabbage. a) 30st October 2021, b) 30st November 2021 c) 30st December 2021 d) 30st January 2022 and e) 28th February 2022

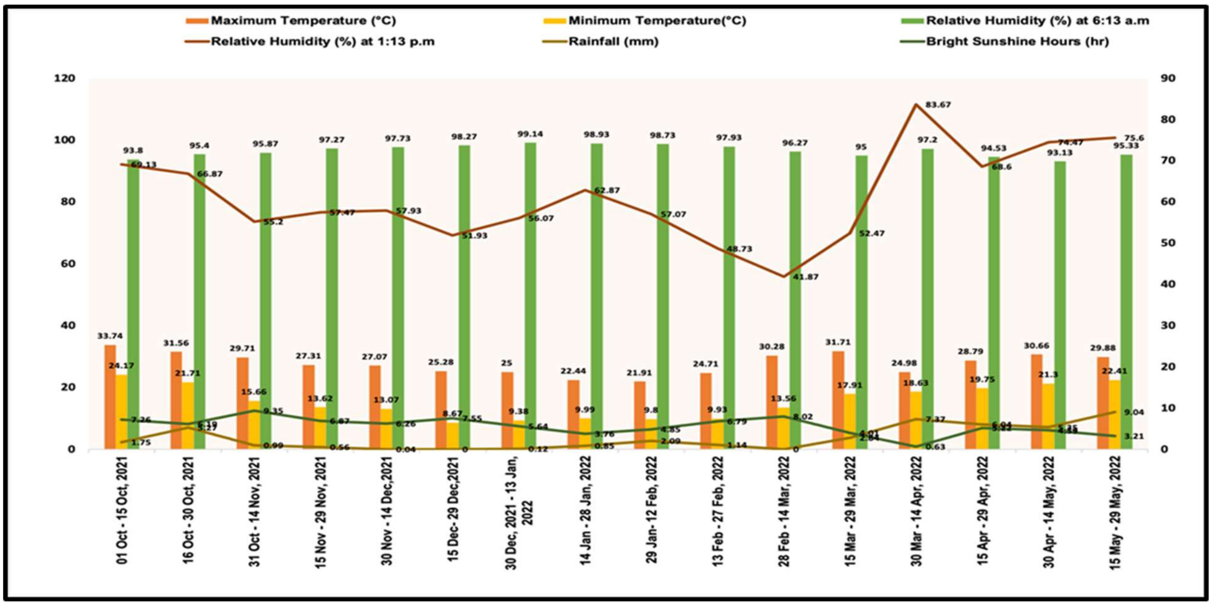

Figure 3: Weather data of Jorhat during the period of experiment taken from Meteorological Observatory, AAU, Jorhat (1st Oct, 2021 to 29th May, 2022)

With regard to the relative humidity recorded in the morning and evening, a significant positive correlation was obtained in all the treatments except for a significant negative correlation in the 30th October (-0.987**) evening relative humidity. A similar positive and significant correlation was obtained in the case of rainfall except in the crop transplanted on 30th December (0.862) where a non-significant positive correlation was found. A significant negative correlation was obtained with respect to the bright sunshine hours (BSSH) except for the crop transplanted on 30th October (-0.795), it showed a non-significant negative correlation. A high correlation was seen in the results of multiple regression analysis between PDI and meteorological variables during the crop season (Table 4). The total influence of all meteorological elements in the changing disease development was shown by the coefficient of multiple determinations (R^2), which ranged from 63.19% to 82.94% for the crop transplanted in October, November, December, January and February, respectively. The prediction equations for all treatments collectively demonstrated that weather factors had a combined influence to the extent of 82.94%, 63.19%, 72.70%, 76.32%, and 70.33%. Specifically, the multiple regression equations used to forecast the disease severity of Alternaria leaf blight in cabbage transplanted from 30th October to 28th February are as follows:

For 30th October transplant: $Y1 = 17.1708 - 0.2833A1 - 1.024A2 + 0.1924A3 + 0.0003A4 + 0.0037A5 - 0.6603A6$
For 30th November transplant: $Y2 = 23.1324 - 0.9045A_1 - 0.6160A_2 + 0.2430A_3 - 0.1080A_4 + 0.3639A_5 - 0.3787A_6$
For 30th December transplant: $Y3 = 15.1262 - 0.7080A_1 - 0.8312A_2 + 0.2981A_3 - 0.0240A_4 + 0.1794A_5 - 0.5203A_6$
For 30th January transplant: $Y4 = 10.5681 - 0.6536A_1 + 0.5426A_2 + 0.2552A_3 + 0.0726A_4 - 0.1356A_5 - 0.4153A_6$
For 28th February transplant: $Y5 = 32.4017 - 0.8132A_1 + 1.0248A_2 + 0.3525A_3 + 0.2167A_4 - 0.0708A_5 + 0.7338A_6$

Table 4: Multiple regression equation for prediction of percent disease index (PDI) of Alternaria leaf spot at five different dates of transplanting of the cultivar Pride of India using different combinations of weather factors

Date of transplanting	Intercept (a)	Regression coefficient (b)						R^2
		Weather factors						
		A_1	A_2	A_3	A_4	A_5	A_6	
30th October	17.1708	-0.2833	-1.024	0.1924	0.0003	0.0037	-0.6603	0.8294
30th November	23.1324	-0.9045	-0.616	0.2430	-0.108	0.3639	-0.3787	0.6319
30th December	15.1262	-0.7080	-0.8312	0.2981	-0.024	0.1794	-0.5203	0.7270
30th January	10.5681	-0.6536	0.5426	0.2522	0.0726	-0.1356	-0.4153	0.7632
28th February	32.4017	-0.8132	1.0248	0.3525	0.2167	-0.0708	0.7338	0.7033

A greater incidence of Alternaria leaf blight of mustard was also noted by Shrestha *et al.* (2005) in meteorological conditions with maximum temperatures of 18°C to 25°C, lowest temperatures of 10°C to 14°C, and relative humidity of more than 80%. Similar findings on the disease caused by *Alternaria brassicae* in the Brassica crop were also reported by Sinha *et al.* (1992) they reported that the disease intensity increases along with the plant age when the temperature ranges between 8-12°C minimum temperature to 21-26°C maximum temperature and 90% RH. According to Gemawat and Prasad (1972), high humidity >90% for around 3 days and a temperature of 23°C to 28°C increase the severity of *Alternaria* causing cumin blight. In their study on the Alternaria leaf spot of safflower, Murumkar *et al.* (2008) also observed that temperatures between 21°C to 33°C, high rainfall, and high humidity >80% had a significant impact on the disease development. During the study, it was observed that relative humidity (morning), relative humidity (evening) and rainfall had a positive correlation with the intensity of Alternaria leaf blight, while the temperature (maximum and minimum), and bright sunshine hours all had a negative correlation. The findings of Gupta *et al.* (2003) were in conformity with our findings. They also observed that the relative humidity (morning and evening) showed a significant positive correlation with disease intensity while the temperature (maximum and minimum) showed a significant negative correlation in the disease intensity of Alternaria blight on rapeseed mustard. In the cluster bean leaf blight, Sharma *et al.* (2020) also found the same kind of correlation matrix. Early studies on the various diseases caused by Alternaria also revealed a negative correlation between temperatures (maximum and minimum) and disease severity, while a positive correlation existed between relative humidity and rainfall (Bajaya *et al.,* 2022; Fagodiya *et al.,* 2022). It might be due to the favourable temperature for spore germination of Alternaria is the temperature in the range of 18°C and 24 °C and relative humidity levels above 90% (Nowicki *et al.,* 2012). The ideal temperature for spore germination of Alternaria, according to Selvamani (2014), was between 20°C and 24°C, with a relative humidity of at least 90%.

Conclusion

The time of transplanting had a considerable impact on the per cent disease intensity of Alternaria leaf blight. In the experimental year, crop transplanted in October had the lowest PDI and AUDPC, whereas the crop transplanted in December had the highest. Early transplanting was found to be beneficial for the farmers for the reduction of Alternaria leaf blight incidence. The development of the disease is significantly influenced by weather variables such as (maximum and minimum) temperatures, (morning and evening) relative humidity, rainfall, and BSSH. Development of a disease forecasting model for Alternaria blight of cabbage based on epidemiological factors becomes the need of the hour for a successful environment friendly disease management strategy.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Assessing the bioefficacy of Cyantraniliprole 10.26% OD against fruit borer and thrips on chilli under field condition

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ABSTRACT

During the *rabi* season of 2020, a trial was performed to estimate the efficacy of Cyantraniliprole 10.26 % OD at different doses (30, 60, 90, and 120 g a.i./ha respectively) together with Imidacloprid 17.8% SL (20 g a.i./ha) and Spinosad 45% SC (73 g a.i./ha) to evaluate their efficacy against the fruit borer and thrips infesting chilli (variety SHP-4884). The trial was performed in randomized block design containing three replications. The results showed that Cyantraniliprole 10.6% OD @ 120 g a.i./ha was the most efficient insecticide among the others and recorded the maximum reduction (84.13 % in larval population of fruit borer and 78.03 % in thrips population) in both the pest populations over the untreated check. However, Cyantraniliprole 10.6% OD @ 90 g a.i./ha was noted as the next best insecticide.

Introduction

In India, chilli (*Capsicum annuum* L.) is a crucial spice covering around 0.81 million hectares of total chilli production (Raj and Christopher, 2009). It is the world's second-most essential vegetable after the tomato and the thick flesh cultivar is comparatively not pungent (Sukhi *et al.,* 2020). When compared to other chilli growing countries, India's crop productivity is quite low, and it is attributed to a number of limiting conditions (Vanisree *et al.,* 2013). Among them, the ravages caused by insect pests are vital ones. This crop is being infested with a wide range of insect pests, of these, mites (*Polyphagotarsonemus latus* (Banks)), aphid (*Aphis gossypii* Glover), jassids (*Amrasca biguttula* Ishida), thrips (*Scirtothrips dorsalis* Hood), and fruit borer (*Helicoverpa armigera* (Hübner)) are the major production constraints of chilli, and causes about 70-80% yield loss (Subhashree *et al.,* 2020).

In recent decades, to gain higher yield and to minimize the chilli's pests, the indiscriminate use of conventional insecticides like organophosphates, synthetic pyrethroids has increased in chilli crop (Nayak *et al.,* 2014). Sometimes, throughout the cropping season, farmers in Southeast Asian nations like Bangladesh and India use more than 30 to 40 rounds of spraying (Alam, 2019a). As a result of this, in addition to pest resurgence, pesticide resistance and the elimination of natural enemies have impeded both domestic consumption and export of chilli (Subhashree *et al.,* 2020). Additionally, the consumption of excessive chemical insecticidal residue harms the ecosystem by causing difficulties with human health, ecological imbalance, water pollution, and the eradication of beneficial wildlife (Gundannavar *et al.,* 2007). Keeping this view and overcoming these problems, therefore, several

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aspects need to be reexamined and evaluated in order to develop a sound management programme with novel or residue-free pesticide usage. There is less information about the efficacy on the insect pests that infest chilli. In this experiment, we have used a newer molecule of insecticides, i.e., Cyantraniliprole 10.26 % OD at different doses to evaluate its effect on the major two pests of chilli *i.e.,* thrips and fruit borer. However, a few workers had previously assessed the field bio-efficacy of Cyantraniliprole at various doses against sucking pests (Patel and Kher, 2012a; Misra 2012; Mandal 2012; Patel and Kher, 2012b) on other crops. Cyantraniliprole (IRAC MoA 28) is a second-generation anthranilic diamide insecticide discovered by DuPont Crop Protection. The 10.6% OD formulation refers to the concentration of Cyantraniliprole in the specific product (oil dispersion formulation) being used. The mode of action of Cyantraniliprole involves targeting the insect's muscular and nervous systems. It selectively acts on the insect ryanodine receptor, which is an important calcium channel involved in muscle contraction and regulation of neuro transmitter release in insects. Though this is a systemic insecticide which is active through both ingestion and contact routes, it is more potent via ingestion (Sattelle *et al.,* 2008; IRAC, 2012). It is the first insecticide to control a crossspectrum of sucking (Hemiptera) and chewing (Lepidoptera) pests (Anonymous, 2012). In the present research, insecticides currently employed to control targeted pests in three consecutive sprayings displayed a varied level of field-efficacy through specific treatment schedules described in detail below.

Material and Methods

The study was operated at Jaguli Instructional Farm (23.56°N; 88.32° E), BCKV (Bidhan Chandra Krishi Viswavidyalaya), West Bengal, during *rabi* season using the chilli variety SHP-4884. The details of the insecticides used for the study are described in Table 1. The crop was grown in the nursery bed for one month before being transplanted in the main field in plots of a 4 m^2 area with a spacing of 45cm x 45cm in the last week of October 2020. All the observations were collected by closely inspecting the leaves and plant growth. Following the target pests' infestation, three successive sprayings were carried out ten days apart. Observations were made one day prior and 3, 7 and 10 days after the spraying of insecticides for counting adults and nymphs of thrips and the larval populations of fruit borer. All observations were registered from five tagged plants using three leaves that covered the plants' bottom, middle and top leaves (Jeyarani and Chandrasekaran, 2006). Analysis of variance was done following randomized block design after suitable transformation. All the statistical tests were performed in the OP Stat, CCS Haryana Agricultural University.

Table 1: The details of the insecticidal treatments

Tr. No.	Insecticide	Formulation	Dosage (g a.i./ha)	Group of Chemical
T_1	Cyantraniliprole	10.6% OD	30	Anthanilic Diamides
T_2	Cyantraniliprole	10.6% OD	60	Anthranilic Diamides
T_3	Cyantraniliprole	10.6% OD	90	Anthanilic Diamides
T_4	Cyantraniliprole	10.6% OD	120	Anthranilic Diamides
T_5	Imidacloprid	17.8% SL	20	Neonicotinoid
T_6	Spinosad	45 % SC	73	Spinosyns
T_7	Untreated control	-	-	-

Results and Discussion

The different treatments used against chilli pests in open field conditions were imposed sequentially at ten days intervals during 2020-21. The results obtained are presented here.

Fruit borer (*Helicoverpa armigera* Hübner):

First spray: The mean numbers of larvae before the starting of spray are significantly similar among different plots (1.12 to 1.96 fruit borer/3 leaves) (Table 2) as the data are statistically nonsignificant ($F_{6,12}$ = 0.40, P = 0.8634) (CD = non-significant; SEm± = 0.15). After 3rd day of spraying, the minimum fruit borer larvae were recorded in T_4 (0.74 fruit borer /3 leaves) and was at par with T_3 (0.80 fruit borer/3 leaves). The treatment of T_7 (2.20 fruit borer/3 leaves) recorded a significantly higher population than the rest of the treatments ($F_{6,12}$ = 5.95, P = 0.0043) (CD = 0.21; SEm± = 0.07). After seven days after the first spraying, T_4 recorded the lowest fruit borer population (0.52 fruit borer/3 leaves) and was also at par with the treatment of T_3 (0.60 fruit borer/3 leaves) ($F_{6,12}$ = 9.07, P = 0.0006) (CD = 0.22; SEm± = 0.07). On the 10th day after spray, T_3 was found to be the most effective treatment (0.53 fruit borer/3 leaves) and was at par with the treatment T_4 (0.62 fruit borer/3 leaves) ($F_{6,12}$ = 10.25, P = 0.0003) (CD = 0.22; SEm± = 0.07). The maximum (2.62 fruit borer population per three leaves) per plant were recorded in the untreated control (Table 2).

Second spray: The mean larvae of the fruit borer population after three days of application of insecticides indicated that T_3 was found to be the most effective treatment, which gave 0.38 mean larvae of the fruit borer population. However, it was statistically at par with T_4 (0.52) and T_2 (0.60) fruit borer/3 leaves ($F_{6,12}$ = 13.98, P = 0.00009) (CD = 0.20; SEm± = 0.07). After seven days of second spraying, T_3 recorded the lowest fruit borer population (0.26 fruit borer/3 leaves) and was also at par with the treatment of T_4 (0.32 fruit borer/3 leaves) ($F_{6,12}$ = 20.60, P = 0.00001) (CD = 0.19; SEm± = 0.06). On the 10th day after spray, T_4 was found to be the most effective treatment (0.38 fruit borer/3 leaves) and was at par with the treatment T_3 (0.40 fruit borer/3 leaves) ($F_{6,12}$ = 23.47, P = 0.00001) (CD = 0.20; SEm± = 0.06). The maximum (3.10 fruit borer population per three leaves) larval population per plant were recorded in the untreated control (Table 2).

Third spray: After three days of the third spray, the maximum mean population of fruit borer was recorded at 2.86 per three leaves per plant in T_7, and the minimum was recorded from T_4 (0.12 fruit borer/3 leaves) and T_3 (0.32 fruit borer/3 leaves) ($F_{6,12}$ = 33.06, P = 0.0000) (CD = 0.17; SEm± = 0.05). After the 7th day of spraying, the larval population was nil in plots treated with T_4, followed by T_3 and T_1 (0.24 and 0.26 fruit borer larvae/3 leaves respectively) ($F_{6,12}$ = 62.97, P = 0.0000) (CD = 0.15; SEm± = 0.05). After ten days of the third spray among the different insecticide treatments, T_4 gave the best result in managing fruit borer populations (0.06 larvae/3 leaves) ($F_{6,12}$ = 25.80, P = 0.0000) (CD = 0.23; SEm± = 0.07) followed by T_3 (0.16 fruit borer larvae/3 leaves) and T_2 (0.22 fruit borer larvae/3 leaves). The maximum (3.42 fruit borer larvae/3 leaves) population was found in the untreated control (Table 2). So, depending on the mean number of fruit borer (larvae), the decreasing efficacy rate of different insecticidal treatments was as follows: $T_4 > T_3 > T_2 > T_6 > T_1 > T_5 > T_7$ (Fig. 1).

Thrips (*Scirtothrips dorsalis* Hood):

First spray: One day before 1st spray, the maximum mean population of thrips was 10.98 /3 leaves in T_7, and the minimum was recorded at 8.98 thrips /3 leaves in T_5 ($F_{6,12}$ = 0.57, P = 0.7468), showed that there was no significant difference of thrips population in different treatments (CD = non-significant; SEm± = 0.15) (Table 3). Three days after spraying, the maximum mean population of thrips was recorded at 11.56 thrips/3 leaves in T_7, and the minimum was 3.38 thrips/3 leaves in T_4 and T_3 (3.62 thrips/3 leaves) ($F_{6,12}$ = 4.515, P = 0.0127) (CD = 0.71; SEm± = 0.23). Seven days after spraying, the maximum mean population of thrips was observed in T_7 (11.82 thrips/3 leaves), and the minimum was recorded in T_4 (2.64 thrips/3 leaves) ($F_{6,12}$ = 6.69, P = 0.0026) (CD = 0.66; SEm± = 0.21). After ten days of the first spray, T_4 gave the best result in managing thrips populations 2.84 thrips/ 3 leaves ($F_{6,12}$ = 8.30, P = 0.0010) (CD = 0.61; SEm± = 0.20) followed by T_3 (3.02 thrips/3 leaves) and T_2 (4.30 thrips/3 leaves).

Table 2: Bio efficacy of Cyantraniliprole 10.6% OD against fruit borer (larval count) on chili during 2020

	Treatment Details	Dose (g.a.i/ Ha)	Pre-treatment	Mean larval populations/ 3 leaves									ROC (%)
				1st Spray*			2nd Spray*			3rd Spray*			
				3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS	
T1	Cyantraniliprole 10.6% OD	30	1.38 (1.53)	1.02 (1.42)	0.72 (1.31)	0.86 (1.36)	0.68 (1.29)	0.54 (1.24)	0.60 (1.26)	0.48 (1.21)	0.26 (1.12)	0.32 (1.15)	74.80
T2	Cyantraniliprole 10.6% OD	60	1.28 (1.50)	0.94 (1.39)	0.68 (1.29)	0.72 (1.31)	0.60 (1.26)	0.48 (1.21)	0.54 (1.24)	0.42 (1.19)	0.34 (1.15)	0.22 (1.10)	77.15
T3	Cyantraniliprole 10.6% OD	90	1.42 (1.55)	0.80 (1.34)	0.60 (1.26)	0.53 (1.23)	0.38 (1.17)	0.38 (1.17)	0.40 (1.18)	0.32 (1.15)	0.24 (1.11)	0.16 (1.08)	81.23
T4	Cyantraniliprole 10.6% OD	120	1.12 (1.45)	0.74 (1.31)	0.52 (1.23)	0.62 (1.27)	0.44 (1.20)	0.32 (1.15)	0.38 (1.17)	0.12 (1.06)	0.00 (1.00)	0.06 (1.03)	84.13
T5	Imidacloprid 17.8 SL	100	1.88 (1.68)	1.34 (1.53)	1.12 (1.45)	1.04 (1.43)	0.86 (1.36)	0.68 (1.29)	0.72 (1.31)	0.56 (1.25)	0.42 (1.19)	0.48 (1.21)	66.57
T6	Spinosad 45% SC	73	1.56 (1.59)	1.10 (1.44)	0.88 (1.37)	0.76 (1.32)	0.62 (1.27)	0.50 (1.22)	0.42 (1.19)	0.38 (1.17)	0.24 (1.11)	0.30 (1.14)	75.17
T7	Untreated control		1.96 (1.70)	2.20 (1.79)	2.38 (1.84)	2.62 (1.90)	2.54 (1.88)	2.78 (1.94)	3.10 (2.02)	2.86 (1.96)	3.36 (2.09)	3.42 (2.09)	0.00
C.D			NS	0.21	0.22	0.22	0.20	0.19	0.20	0.17	0.15	0.23	
SEm±			0.15	0.07	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.07	
F_{cal}			0.403	5.950	9.073	10.250	13.983	20.605	23.471	33.066	62.970	25.806	
P			0.8634	0.00437	0.00069	0.00039	0.00009	0.00001	0.00001	0.00000	0.00000	0.00000	

Values in the parenthesis are square root transformed. NS – Nonsignificant, DAS - Days After Spray. ROC – Mean reduction over control.
(*) - Mean value

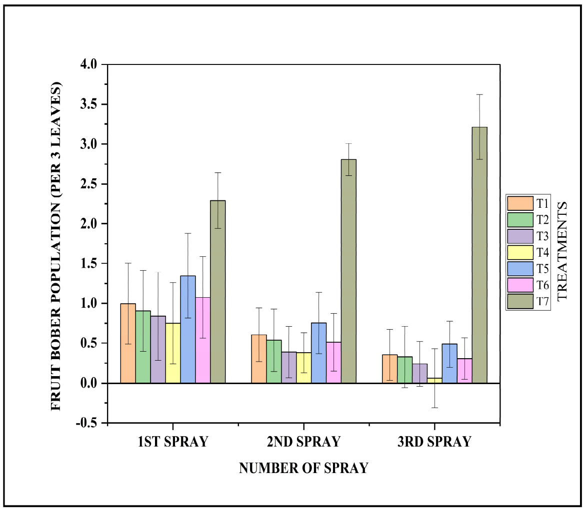

Fig. 1: Graphical representation of the effect of insecticides on the population of chilli fruit borer in three different insecticidal sprayings

The maximum thrips population (12.10 thrips/ 3 leaves) was found in untreated control which was significantly higher than all other insecticidal treatments.

Second spray: On the 3rd day of the second spray, the thrips population ranges from 1.98 to 11.92 per three leaves per plant ($F_{6,12}$ = 7.76, P = 0.0014) (CD = 0.69; SEm± = 0.22) (Table 3). It is observed that, at the end of the 7th and 10th days of spraying, the decreasing trend in the population of thrips followed the results of the first spray and T_4 recorded the maximum reduction in the mean population of thrips ($F_{6,12}$ = 16.31, P = 0.0000; $F_{6,12}$ = 15.98, P = 0.0000 respectively) (CD = 0.51, SEm± = 0.17; CD = 0.50; SEm± = 0.16) which was immediately followed by T_3.

Third spray: On the third day after the 3rd spray, the thrips population ranges from 0.82 to 12.34 per three leaves per plant. the maximum mean population of thrips was recorded in T_7 (12.34 thrips/3 leaves), and the minimum was recorded in T_4 (0.82 thrips/3 leaves) and T_3 (1.58 thrips/3 leaves) ($F_{6,12}$ = 12.99, P = 0.0001) (CD = 0.65; SEm± = 0.21). Then, seven days after the third spray, the maximum mean population of thrips was 12.58 thrips/3 leaves observed in T_7 ($F_{6,12}$ = 14.37, P = 0.0000) (CD = 0.66; SEm± = 0.21), and the minimum was recorded in T_4 (0.64 thrips/3 leaves) (Table 3). After ten days of the third spraying among the different insecticide treatments, T_3 recorded the minimum number of thrips populations (0.90 thrips/3 leaves) followed by T_4 (0.98 thrips/3 leaves) and T_6 (1.98 thrips/3 leaves) ($F_{6,12}$ = 21.26, P = 0.0000) (CD = 0.54; SEm± = 0.17). So, depending on the mean number of thrips (adult and nymph), the decreasing efficacy rate of different insecticidal treatments was as follows: $T_4 > T_3 > T_2 > T_6 > T_1 > T_5 > T_7$ (Fig. 2). Insecticide resistance poses a noteworthy concern in the context of effective pest management programs. To address this challenge, resistance management strategies are currently in development, focusing on incorporating safer and newer chemical agents and implementing insecticide rotation modules. A critical facet of resistance management for chilli pests involves the judicious use of chemicals to which resistance has already manifested and the incorporation of novel modes of action. Among the emerging class of insecticides, cyantraniliprole stands out with its unique mode of action, holding significant potential for integration into existing pest management protocols (Tiwari and Stelinski, 2013). Cyantraniliprole belongs to the anthranilic diamide class of chemistry and represents the second active ingredient within this class to be commercialized for the control of a diverse spectrum of pests, encompassing both chewing and sucking insect species (such as leafminers, leaf-feeding beetles, fruit flies, whiteflies, psyllids, and lepidopteran insects) (Lahm *et al.,* 2013; Selby *et al.,* 2013; Lahm *et al.,* 2007; Cordova *et al.,* 2006; Lahm *et al.,* 2005). Notably, cyantraniliprole has exhibited effectiveness in managing insect pests while potentially exerting a lesser detrimental impact on natural enemies populations when compared to conventional broad-spectrum chemical agents. The strategic application of cyantraniliprole during specific times of the year may contribute to the preservation of biological control agents, distinguishing it from alternative broad-spectrum chemicals (Tiwari and Stelinski, 2013). The present field experiment has further substantiated the efficacy of foliar cyantraniliprole applications at different dosages in mitigating populations of fruit borer and thrips in chilli. Our findings underscore the promising broad-spectrum activity of cyantraniliprole within the context of chilli pest management strategies.

Table 3: Bio efficacy of Cyantraniliprole 10.6% OD against thrips (adult and nymph count) on chili during 2020

	Treatment Details	Dose (g.a.i/ Ha)	Pre-treatment	Mean thrips population/ 3 leaves									ROC (%)
				1st Spray*			2nd Spray*			3rd Spray*			
				3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS	3 DAS	7 DAS	10 DAS	
T1	**Cyantraniliprole 10.6% OD**	**30**	10.56 (3.39)	5.30 (2.48)	4.76 (2.39)	4.66 (2.36)	3.80 (2.16)	3.62 (2.14)	3.50 (2.10)	2.28 (1.80)	2.14 (1.76)	2.32 (1.81)	**64.41**
T2	**Cyantraniliprole 10.6% OD**	**60**	9.40 (3.22)	4.74 (2.38)	4.16 (2.26)	4.30 (2.28)	3.62 (2.12)	3.16 (2.02)	3.32 (2.07)	2.42 (1.83)	2.08 (1.71)	2.28 (1.79)	**67.28**
T3	**Cyantraniliprole 10.6% OD**	**90**	10.02 (3.32)	3.62 (2.12)	3.14 (2.01)	3.02 (1.98)	2.38 (1.82)	1.94 (1.69)	2.06 (1.73)	1.58 (1.58)	1.12 (1.45)	0.90 (1.37)	**75.32**
T4	**Cyantraniliprole 10.6% OD**	**120**	9.12 (3.18)	3.38 (2.07)	2.64 (1.89)	2.84 (1.95)	1.98 (1.71)	1.72 (1.64)	2.34 (1.82)	0.82 (1.34)	0.64 (1.28)	0.98 (1.39)	**78.07**
T5	**Imidacloprid 17.8 SL**	**100**	8.98 (3.16)	5.82 (2.60)	5.12 (2.46)	4.86 (2.42)	3.98 (2.22)	3.70 (2.15)	3.84 (2.19)	3.08 (1.98)	2.74 (1.91)	3.12 (2.02)	**62.51**
T6	**Spinosad 45% SC**	**73**	10.46 (3.38)	5.12 (2.46)	4.64 (2.34)	4.42 (2.31)	3.76 (2.16)	3.54 (2.12)	3.62 (2.14)	2.36 (1.81)	2.12 (1.72)	1.98 (1.71)	**65.17**
T7	**Untreated control**		10.98 (3.45)	11.56 (3.53)	11.82 (3.57)	12.10 (3.62)	11.92 (3.58)	12.24 (3.63)	12.42 (3.65)	12.34 (3.64)	12.58 (3.67)	12.70 (3.70)	**0.00**
C.D			**NS**	**0.71**	**0.66**	**0.61**	**0.69**	**0.51**	**0.50**	**0.65**	**0.66**	**0.54**	
SEm±			**0.15**	**0.23**	**0.21**	**0.20**	**0.22**	**0.17**	**0.16**	**0.21**	**0.21**	**0.17**	
F_{cal}			**0.570**	**4.515**	**6.695**	**8.307**	**7.761**	**16.316**	**15.980**	**12.994**	**14.376**	**21.267**	
P			**0.74682**	**0.01276**	**0.00268**	**0.00104**	**0.00141**	**0.00004**	**0.00004**	**0.00012**	**0.00007**	**0.00001**	

Values in the parenthesis are square root transformed. NS – Nonsignificant, DAS - Days After Spray. ROC – Mean reduction over control. (*) - Mean value

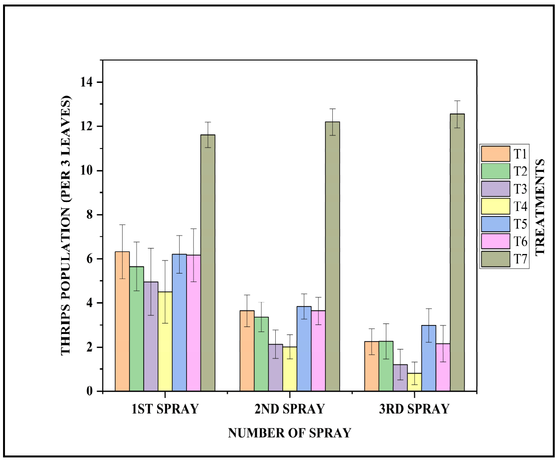

Fig. 2: Graphical representation of the effect of insecticides on the population of chilli thrips in three different insecticidal sprayings

The results indicate that cyantraniliprole @ 120 g a.i. ha^{-1} and 90 g a.i. ha^{-1} reduces the larval population of chilli fruit borer by 84.13 % and 81.23 %, respectively, and these observations are in conformity with Kodandaram *et al.* (2015) where they clearly showed the effectiveness of cyantraniliprole @ 105 g a.i. ha^{-1} was found most effective and recorded significantly lowest per cent fruit damage against *Leucinodes orbonalis,* followed by cyantraniliprole @ 90 g a.i. ha^{-1} during 2010 and 2011. Mandal (2012) also reported Cyazypyr 10% OD @ 105 and 90 g a.i. ha^{-1} was highly effective against the fruit borer in tomato. Yadav *et al.* (2012) recorded the highest leaf damage reduction by flea beetle, *Scelodonta strigicollis* in grapes against cyantraniliprole @ 80 ga.i./ha. Tiwari *et al.* (2013) acknowledged that foliar application of cyantraniliprole reduced the numbers of *Diaphorina citri* adults and nymphs in citrus. Mishra and Mukherjee (2012) revealed that Cyazypyr 10% OD @ 105 and 90 g a.i. ha^{-1} to be most effective against red pumpkin beetles *Aulacophora foveicollis* on gherkins. All these findings support the present investigation and are very similar to the obtained results. Cyantraniliprole also have a compound movement through the leaf cuticle, which includes reduced losses through wash-off, volatilization and photodegradation, thus potentially providing improved coverage and better residual activity on target pests (Stevens et al., 1988; Buchholz and Nauen, 2002). In our results, the mean reduction of thrips over control was maximum in cyantraniliprole @ 120 g a.i. ha^{-1} (78.07 %) and cyantraniliprole @ 90 g a.i. ha^{-1} (75.32 %). This similar finding was also reported by Patel *et al*. (2014), where they reported cyantraniliprole 10% OD at 105 g a.i./ha was noted as more potent in minimizing thrips in chilli, and it was at par with cyantraniliprole 10% OD at 90 g a.i./ha. Misra (2012) also found that both the doses of cyantraniliprole, *i.e.,* 105 and 90 g a.i./ha, were equally effective against *T. tabaci* infesting tomato. Hence, it becomes imperative to assess the compatibility of insecticides within diverse cropping systems as part of an overarching effort to reduce environmental impacts while maintaining favourable toxicological profiles and employing minimal application rates. The current study represents a fundamental element of our broader objective, which revolves around the ongoing enhancement and refinement of integrated pest management strategies specifically designed to combat the fruit borer and thrips infestations in chilli cultivation.

Conclusion

To conclude, we can say that the findings indicate all the pesticide treatments were more successful than the control in lowering the thrips and fruit borer populations. The efficacy of Cyantraniliprole 10.6% OD is due to its root systemic activity with some translaminar movement. It is effective against the larval stages of lepidopteran insects, thrips, aphids, and some other chewing and sucking insects. Due to its selective mode of action, it is non only effective against targeted pests, but also safe to non-target arthropods and conserves natural parasitoids, predators and pollinators. So, Cyantraniliprole 10.6% OD @ 120 g a.i./ha can be a good substitute chemical to traditional insecticides for faster controlling, followed by Cyantraniliprole 10.6% OD @ 90 g a.i./ha. The dual activity of cyantraniliprole against both sucking and chewing insect pests underscores its significance in the context of integrated pest management (IPM) and insect resistance management (IRM) strategies. To ensure the continued viability of these compounds as a pest management option for farmers, it becomes imperative to implement comprehensive IPM and IRM practices.

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Conflict of interest
The authors declare that they have no conflict of interest.

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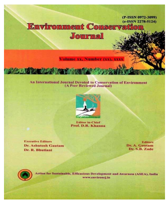

In-vitro evaluation of fungicides against *Alternaria burnsii* (Uppal, Patel and Kamat) causing blight of cumin (*Cuminum cyminum* L.)

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ABSTRACT

The present investigation aimed to determine the per cent growth inhibition of different fungicides against *Alternaria burnsii*, the causal agent of cumin blight. The study was conducted during 2020-21 at the Experiential Unit of Plant Pathology, College of Agriculture, SKRAU, Bikaner. Using the poisoned food technique, eleven fungicides were tested at varying concentrations (100, 200, 300, and 500 ppm). After seven days of incubation, the radial growth and per cent growth inhibition of *A. burnsii* were measured. The results revealed that increasing the fungicide concentration led to greater inhibition of mycelium growth. Among the tested fungicides, Tebuconazole 50% + Trifloxystrobin 20% WG exhibited the highest mean inhibition (76.94%), followed by Tebuconazole 2DS (65.09%) and Pyraclostrobin 13.30% + Epoxiconazole 5% SE (58.75%). Notably, Tebuconazole 50% + Trifloxystrobin 20% WG at concentrations of 300 ppm and 500 ppm, as well as Tebuconazole 2DS at 500 ppm, demonstrated the highest effectiveness with cent per cent growth inhibition. On the other hand, Chlorothalonil showed the least mean growth inhibition (22.96%). The results demonstrated that as the fungicide concentration increased, there was a corresponding increase in the inhibition of *A. burnsii* growth. These findings highlight the potential effectiveness of selected fungicides, particularly Tebuconazole 50% + Trifloxystrobin 20% WG and Tebuconazole 2DS for managing cumin blight caused by *A. burnsii.*

Introduction

Cumin (*Cuminum cyminum*) is an aromatic spice widely used in culinary applications and known for its distinctive flavour and aroma. It is a popular ingredient in various cuisines worldwide and has been valued for its medicinal properties for centuries. Cumin seeds contain essential oils, antioxidants, and bioactive compounds contributing to their flavour, aroma, and potential health benefits. Cumin, a widely cultivated crop, faces various diseases that pose significant challenges to its productivity. Among the most prominent diseases affecting cumin are blight, wilt, and powdery mildew, which result in substantial yield losses (Dange, 1995). Blight, in particular, is a widespread and devastating problem that occurs annually in many cumin-growing regions. This disease spreads rapidly during humid and cloudy weather conditions, lacking effective control measures and causing yield losses of up to 80% (Gemawat and Prasad, 1972). Unfortunately, none of the existing cumin varieties exhibits resistance to blight, making it a quick-spreading and destructive threat that affects all parts of the plant, including the seeds. The cumin blight-causing pathogen *Alternaria burnsii* was first identified in India (Uppal *et al.*, 1938) and subsequently reported in Pakistan (Shakir *et al.,* 1995). Research studies have demonstrated the significant impact of blight on cumin crops. In a study conducted by Kakraliya *et al.,* (2021) in Rajasthan, it was observed that

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cumin crops faced a substantial setback under favorable conditions, experiencing 62.88 per cent decrease in yield due to the presence of Alternaria blight. In another study conducted by Wadud *et al*., 2021, it was found that blight of cumin caused a drastic yield loss, with an incidence rate of nearly 98 per cent and a disease severity of up to 88 per cent. There can be many approaches to managing cumin blight, which includes different fungicides, plant extract, or bioagents (Jagani *et al.,* 2023). While management through biological agents and botanicals is considered an eco-friendly approach for disease control, their effectiveness against the pathogen is often unsatisfactory, resulting in poor disease management outcomes (Yadav *et al.,* 2022). The evaluation of fungicides plays a crucial role in effectively managing cumin blight, as it is a severe fungal disease. Fungicides are chemical compounds specifically formulated to control fungal diseases and can serve as effective tools in combating blight in cumin crops (Kakraliya *et al.,* 2021). While several broad-spectrum fungicides have been previously reported for their *in-vitro* efficacy against Alternaria blight of cumin, it is vital to assess their relative effectiveness compared to new-generation fungicides. This evaluation will contribute to a better understanding of the *in-vitro* efficacy of both individual fungicides and new combinations, aiming for more effective management of cumin blight.

Material and Methods

A total of eleven fungicides (Table 1) were evaluated for their effectiveness against *Alternaria burnsii* using the poisoned food technique (Nene and Thapaliyal, 1993) at the Experiential Unit of Plant Pathology, College of Agriculture, SKRAU, Bikaner during 2020-21. Four different doses of fungicides (100, 200, 300 and 500 ppm) were used.
The fungicides were accurately measured to achieve concentrations of 100, 200, 300, and 500 ppm. These fungicides were thoroughly mixed with molten Potato Dextrose Agar (PDA) medium, which was then poured into sterilized 90 mm Petri plates. Each plate received 20 ml of the fungicide-amended medium and was allowed to solidify, ensuring uniform distribution.
For the experiment, three replications of each treatment were selected. Actively growing cultures of *A. burnsii*, aged seven days, were used. From the periphery of the cultures, 5 mm diameter discs were aseptically cut using a cork borer. The Petri plates containing the fungicide-amended medium were then aseptically inoculated with these 5 mm discs of *A. burnsii*. Control plates without fungicide treatment were also prepared for comparison purposes. The experimental design followed a completely randomized design (CRD) with three replications for each treatment. Incubation of the inoculated Petri plates took place at a temperature of 28 ± 2 °C in BOD. After a period of seven days, when the control plates exhibited significant fungal growth, the colony diameters were measured. The control and treatment plates were measured to accurately determine the colony diameters. To evaluate the efficacy of the fungicides, the per cent inhibition of mycelial growth was calculated using Bliss's formula (1934):

$$\textbf{Per cent inhibition (I)} = \frac{(\mathrm{C}-\mathrm{T})}{\mathrm{C}} X\ 100$$

Where,
I = Per cent inhibition
C = Colony diameter in control
T = Colony diameter in treatment

Table 1: Fungicides used in lab condition

S.N	Name of fungicide
1.	Tebuconazole 50% +Trifloxystrobin 20% WG
2.	Tebuconazole 2DS
3.	Pyraclostrobin 13.3%+ Epoxiconazole 5% SE
4.	Carbendazim 12% + Mancozeb 63% WP
5	Carbendazim 25% + Iprodione 25% WP
6.	Captan 70% + Hexaconazole 5% WP
7.	Mancozeb 75% WP
8.	Hexaconazole 5% EC
9.	Propiconazole 25% EC
10.	Pyraclostrobin 20 WG + Azoxystrobin 23% SC
11.	Chlorothalonil 75% WP

Results and Discussion

The data presented in Table 2 demonstrates the radial growth and percentage growth inhibition of various fungicides at different concentrations against *Alternaria burnsii*. In the present study, statistical analysis was conducted using analysis of variance (ANOVA) with a significance level of 0.05 (α=0.05). Post-hoc multiple comparison tests were performed to assess significant differences between the treatments. The critical difference (CD) at $P \leq 0.05$ and the coefficient of variation (CV%) were calculated as measures of the level of significance and variation, respectively.

According to the results of the statistical analysis (Table 2), significant differences ($P \leq 0.05$) were observed in the mycelial growth inhibition of *Alternaria burnsii* among different fungicides and their concentrations. The mean radial growth and per cent growth inhibition values were used to compare the effectiveness of each fungicide treatment. The results reveal that an increase in the concentration of fungicides led to greater inhibition of the mycelial growth of the fungus. Among the tested fungicides, Tebuconazole 50% + Trifloxystrobin 20% WG exhibited superior performance in inhibiting the growth of *Alternaria burnsii* at all four concentrations, with a mean percentage inhibition of 76.94%, followed by Tebuconazole 2DS (65.09%) and Pyraclostrobin 13.3% + Epoxiconazole 5% SE (58.7%). Conversely, the fungicides Propiconazole 25% EC (29.81%) and Pyraclostrobin 20 WG + Azoxystrobin 23% SC (25.56%) demonstrated comparatively less effectiveness in inhibiting mycelial growth. Besides this, Chlorothalonil recorded the least per cent inhibition of mycelium growth at all the concentrations, with a (22.96%) mean growth inhibition.

Analyzing the individual concentrations, at 100 ppm, Tebuconazole 50% + Trifloxystrobin 20% WG showed the maximum percentage inhibition (52.23%), followed by Tebuconazole 2DS (48.14%), with Chlorothalonil recording the lowest percentage inhibition (11.12%). At 200 ppm, Tebuconazole 50% + Trifloxystrobin 20% WG displayed 55.56% growth inhibition, followed by Tebuconazole 2DS (52.23%), while Chlorothalonil 75% WP demonstrated the least percentage inhibition (13.70%). At 300 ppm, Tebuconazole 50% + Trifloxystrobin 20% WG exhibited complete growth inhibition, followed by Tebuconazole 2DS (60.00%), and Chlorothalonil showed the least percentage inhibition (18.14%). At 500 ppm, both Tebuconazole 50% + Trifloxystrobin 20% WG and Tebuconazole 2DS displayed complete inhibition, with Pyraclostrobin 13.3% + Epoxiconazole 5% SE showing a high per cent inhibition (83.34%), and Chlorothalonil recording the lowest (48.89%). It is of significance to observe that all the examined fungicides effectively inhibited the mycelial growth of *Alternaria burnsii.*

Among all the fungicides, Tebuconazole 50% + Trifloxystrobin 20% WG demonstrated the highest efficacy in inhibiting the growth of *A. burnsii* at all concentrations, followed by Tebuconazole 2DS. A comparable investigation pertaining to Alternaria blight caused in cumin and other crop was undertaken by several researchers, and their findings have exhibited consistent agreement.

For instance, Rajvanshi *et al.,* (2020) evaluated the efficacy of six different fungicides against *Alternaria brassicae in vitro* and found Tebuconazole 50% + Trifloxystrobin 20% WG and Tebuconazole 250 EC to be the most effective, resulting in complete inhibition of mycelium growth. Saha *et al.,* (2018) conducted comprehensive *in vitro* and *in vivo* studies on *Alternaria brassicae* and observed that Tebuconazole 50% + Trifloxystrobin 20% WG at a concentration of 300 ppm exhibited the most significant inhibition of the pathogen, with its lower dose at 250 ppm also demonstrating notable inhibitory effects. These findings highlight the potential of the Trifloxystrobin-Tebuconazole combination as an effective treatment option for managing *Alternaria* sp.

Shekhawat *et al.,* (2013) investigated the efficacy of four different fungicides against five *Alternaria burnsii* isolates and found that Tebuconazole exhibited the highest efficacy in inhibiting mycelium growth at various concentrations (250, 500, and 1000 ppm). Similarly, Pipliwal *et al.,* (2017) assessed the efficacy of 14 different fungicides *in vitro* and observed that Tebuconazole, Hexaconazole, and Propiconazole demonstrated complete growth inhibition at various concentrations (50, 100, 250, and 500 ppm).

Table 2: Effect of fungicides on mycelial growth inhibition of *Alternaria burnsii* after seven days of incubation

S N	Name of fungicide	Radial Growth (mm)				Per cent Growth Inhibition				
		100 PPM	200 PPM	300 PPM	500 PPM	100 PPM	200 PPM	300 PPM	500 PPM	Mean
1.	Tebuconazole 50% +Trifloxystrobin 20% WG	43.00	40.00	0.00	0.00	52.23 (46.25) *	55.56 (48.17)	100 (90.00)	100 (90.00)	76.94
2.	Tebuconazole 2DS	46.67	43.00	36.00	0.00	48.14 (43.92)	52.23 (46.25)	60.00 (50.74)	100 (90.00)	65.09
3.	Pyraclostrobin 13.3%+ Epoxiconazole 5% SE	49.00	44.67	40.00	15.00	45.55 (42.43)	50.37 (45.19)	55.56 (48.17)	83.34 (65.88)	58.70
4.	Carbendazim 12% + Mancozeb 63% WP	56.00	48.00	43.00	18.67	37.70 (37.90)	46.67 (43.07)	52.23 (46.25)	79.25 (62.88)	53.98
5.	Carbendazim 25% + Iprodione 25% WP	65.67	62.00	47.00	21.67	27.03 (31.28)	31.12 (33.88)	47.78 (43.70)	75.92 (60.36)	45.37
6	Captan 70% + Hexaconazole 5% WP	70.67	68.67	55.34	24.67	21.48 (27.59)	23.70 (29.12)	38.51 (38.34)	72.59 (58.40)	39.07
7.	Mancozeb 75% WP	72.00	69.66	60.67	27.34	20.00 (26.53)	22.59 (28.33)	32.59 (34.78)	69.62 (56.53)	36.20
8.	Hexaconazole 5% EC	75.67	72.66	65.67	31.00	15.92 (23.50)	19.25 (26.01)	27.03 (31.31)	65.55 (54.04)	31.94
9.	Propiconazole 25% EC	77.34	73.34	67.34	34.67	14.07 (22.00)	18.51 (25.46)	25.18 (30.09)	61.48 (51.61)	29.81
10.	Pyraclostrobin 20 WG + Azoxystrobin 23% SC	78.67	76.00	71.67	41.67	12.59 (20.77)	15.56 (23.19)	20.37 (26.68)	53.70 (47.10)	25.56
11.	Chlorothalonil 75% WP	80.00	77.67	73.67	46.00	11.12 (19.44)	13.70 (21.71)	18.14 (25.20)	48.89 (44.34)	22.96
12.	Control	90.00	90.00	90.00	90.00	0.00	0.00	0.00	0.00	0.00
	S Em (±) CD (P≤0.05) CV (%)					0.60 1.77 3.67	0.57 1.67 3.20	0.85 2.51 3.82	0.38 1.13 1.18	

***Values in parenthesis are angular transformed value**

Additionally, Pranaya *et al.,* (2021) conducted an *in vitro* study to assess the effectiveness of five systemic fungicides, including Tebuconazole and Propiconazole, against *Alternaria* sp., with both fungicides demonstrating complete inhibition of mycelium radial growth at concentrations of 500 and 1000 ppm. The findings presented by Jia *et al.,* (2022) further corroborate the significance of TFS-TBZ (Trifloxystrobin-Tebuconazole) as a practical and potent means to combat *Alternaria* sp. Trifloxystrobin-Tebuconazole has emerged as a widely employed fungicide, combining specific ratios of Trifloxystrobin and Tebuconazole. Through their synergistic action, TFS-TBZ has demonstrated remarkable effectiveness in countering *Alternaria* sp., a prevalent fungal pathogen with significant implications for crop health and productivity. Trifloxystrobin-Tebuconazole operates through a combined mode of action, leveraging the effects of its two active ingredients, Trifloxystrobin and Tebuconazole. Trifloxystrobin, belonging to the strobilurin class of fungicides, disrupts the mitochondrial respiration of fungal pathogens by binding to the Qo site of the cytochrome b complex in their electron transport chain. This interference inhibits ATP synthesis, curtailing fungal growth and propagation. Tebuconazole, a triazole fungicide, acts as a demethylation inhibitor, impeding the biosynthesis of ergosterol in the fungal cell membranes. By blocking the enzyme CYP51, tebuconazole disrupts the production of ergosterol, leading to membrane instability, cell leakage, and eventual pathogen death. The synergistic interaction between Trifloxystrobin and Tebuconazole amplifies their individual effects, augmenting the overall fungicidal activity of Trifloxystrobin-Tebuconazole and providing a potent tool for combating a wide range of fungal diseases while reducing the risk of resistance development. While Tebuconazole based fungicides demonstrated promising results, it is essential to consider the efficacy of other fungicides as well. For instance, Mancozeb 75% WP and Carbendazim 12% + Mancozeb 63% WP also showed effectiveness against *Alternaria burnsii* with mean growth inhibitions of 36.20% and

53.98%, respectively. However, it is worth noting that broad-spectrum fungicides like Mancozeb, Carbendazim, and Copper oxychloride have limitations due to their limited persistence on foliage and the potential development of pathogen resistance. In light of these limitations, the use of newer fungicides, such as Trifloxystrobin-Tebuconazole or Tebuconazole-based fungicides with newer modes of action, should be considered to ensure effective disease management and minimize the risk of resistance development. Further research and field evaluations are necessary to determine the long-term efficacy and sustainability of these newer fungicide options in managing *Alternaria burnsii* and other similar pathogens.

Conclusion

The findings highlight the potential efficacy of selected fungicides, particularly Tebuconazole 50% + Trifloxystrobin 20% WG and Tebuconazole 2DS, for managing cumin blight caused by *A. burnsii*. To ensure effective disease management and sustainability, it is crucial to explore newer fungicide options with different modes of action, such as Trifloxystrobin-Tebuconazole or Tebuconazole-based fungicides. Further research and field evaluations are warranted to assess the long-term efficacy and practical applicability of these newer fungicide combinations in managing cumin blight and similar fungal pathogens.

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Conflict of interest

The authors declare that they have no conflict of interest.

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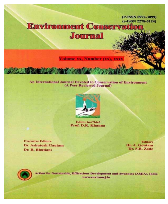

Study of heterosis for grain yield and its components in wheat (*Triticum aestivum* L. em. Thell.)

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ABSTRACT

The extent of wheat heterosis was determined by synthesizing 45 hybrids in a 10×10 diallel method, eliminating reciprocals, to determine how widespread it is. The 57 entries that made up the experimental material—10 parents, 45 crosses and 2 checks (HD 3086 and UP 2628), were assessed over the course of *rabi* 2018–19 using a Randomized Block Design (RBD) with three replications, and observations were made for 12 characters. For yield and its component traits, analyses of heterosis over mid parent, better parent and two standard checks were conducted. ANOVA exposed that there was a high significance existed among all the genotypes for all the characters studied. Yield and its contributing traits have been evaluated for their maximum heterotic range. One cross *i.e.,* CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2* KAU2/6/...×PBW 692 showed positive significance for relative heterosis, heterobeltiosis and standard heterosis over both checks for grain yield per plant. In terms of the number of productive tillers per plant and the number of grains per spike, UP 2901×QLD 73 was found to be a superior heterotic F_1. By displaying a negative significant standard heterosis over both checks, the cross between CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/...×UP 2901 demonstrated its earliness. The desired significant relative heterosis, heterobeltiosis and standard heterosis for spike length were present in HD 3234×UP 2762. The finest heterotic cross combinations for harvest index were determined to be CAL/NH//H567.71/3/SER1/4/CAL /NH//H567.71/5/2* KAU2/6/...×UP 2762 and VORB/SOKOLL×QLD 73. Higher heterotic crossings may be used to identify transgressive segregants that will increase bread wheat production and yield-contributing characteristics.

Introduction

Wheat (*Triticum aestivum* L. em. Thell.) is the main staple food consumed by billions of people worldwide having utmost importance to both the general welfare and national security of many nations. It is known as the “Stuff of life” or “King of cereals” due to the amount of land it takes up, its great productivity and its significant position in the global food grain trade. Due to rising processed food consumption brought on by global industrialisation and the westernization of cuisine, the demand for wheat is rising daily on a global scale. By 2050, the country's population growth would require more than 140 million tonnes of wheat grain, a 40% increase above current output levels (Singh *et al.,* 2019). Not only is a large increase in production necessary to fulfil the rising local food demand, but it is also necessary for export in order to earn foreign currency. This can be done via horizontal strategy, such as expanding the area under cultivation or a vertical approach, such as varietal or hybrid development, which is one of the most effective tools for increasing yield

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and productivity under various agroclimatic conditions. The cycle of stagnant wheat productivity around the world may be broken via heterosis breeding (Adhikari *et al.,* 2020). The key to increasing wheat production potential is heterosis manipulation. The study of heterosis aids in the early generational elimination of the less productive crossings and finds the parents that result in the best cross combinations with the highest expression of heterosis. The current research will help in assessing the extend of heterosis along with the selection of suitable parents for hybridization programme for the production of superior transgressive segregants with higher yield potential in various wheat crossings.

Material and Methods

Ten genetically diverse parents (CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/ 5/2*KAU2/6/…, HD 3234, PBW 692, HUW 640, DBW 189, VORB/SOKOLL, UP 2762, UP 2901, QLD 73, QLD 65) were crossed in half diallel fashion and a total of 45 crosses were developed. The 10 parental lines along with 45 F_1's and two checks (HD 3086 and UP 2628) were evaluated in *rabi* 2018-19 in RBD with 3 replications at Norman E. Borlaug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India. The row to row spacing was 20cm with plant to plant spacing of 10cm and each entry per replication was planted in a single plot of 2 rows having 1m length. The recommended package of practices and cultural operations were followed (Dhar, 2014)The observations were recorded on 12 traits *viz.*, days to 75% heading, days to maturity, flag leaf area (cm^2), number of productive tillers per plant, plant height (cm), spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight (g), biological yield per plant (g), grain yield per plant(g) and harvest index (%). Five plants were selected randomly from each entry per replication for all the traits except days to 75% heading and days to maturity which were recorded on basis of whole plot observation (Roy *et al.,* 2021).

Statistical Analysis

ANOVA was performed by using the mean values for all the characters to test whether there exists a significant difference between the treatments or not (Sharma *et al*., 2018). The heterosis was calculated (in per cent) as increase or decrease in relation to average parent, mid parent and check parent. The formulae used are given below:

$$\textit{Relative}\ \textbf{Heterosis} = \left\{\frac{\overline{F_1} - \overline{MP}}{\overline{MP}}\right\} \times 100$$

$$\textit{Heterobeltiosis} = \left\{\frac{\overline{F_1} - \overline{BP}}{\overline{BP}}\right\} \times 100$$

$$\textit{Standard}\ \textbf{Heterosis} = \left\{\frac{\overline{F_1} - \overline{SP}}{\overline{SP}}\right\} \times 100$$

Where,

$\overline{F_1}$ = *Mean* value of F_1 hybrid

$\overline{MP}$ = Mid parental value

$\overline{BP}$ = Mean performance of better parent

$\overline{SP}$ = Mean performance of standard variety

Results and Discussion

An additional chance to enhance and produce hybrids for yield traits together with adaptability for particular production environment is provided by the exploitation of hybrid vigor for yield and yield attributing traits. The extremely significant mean square estimates for every attribute under study show that there are substantial genetic variations between the genotypes. The results of the ANOVA (Table 1) showed that all characters except the number of spikelets per spike had significant mean sums of squares related to all genotypes. Additionally, all traits except spike length, days to maturity, and the number of spikelets per spike were significant for the mean squares owing to parents, while all traits were significant for the crosses except spike length. While flag leaf area, number of tillers per plant, plant height, spike length, number of grains per spike and biological yield per plant were significant due to mean squares related to parents v/s crosses. The degree of heterosis, which helps determine which parents to use to produce superior F_1 offspring, provides information on the genetic diversity of the parents involved in a cross. The commercial use of heterosis in plant breeding is thought to be an excellent application of genetics in agriculture. It is crucial for determining the course of upcoming breeding programs and for choosing promising cross combinations to obtain superior segregates in later generations in order to further increase wheat grain yield.

Table 1: Mean squares for twelve characters in wheat

SN	Characters	Replication [2]	Genotype [54]	Parent [9]	Crosses [44]	Parent v/s crosses [1]	Error [108]
1	Days to 75% heading	5.097**	6.035**	7.867**	5.796**	0.066	0.961
2	Days to maturity	7.255	6.404**	5.737	6.661**	1.094	2.971
3	Flag leaf area (cm^2)	26.823	43.530**	30.318**	44.154**	134.968**	11.370
4	Number of productive tillers per plant	28.291*	42.635**	12.089	37.164**	558.307**	7.909
5	Plant height (cm)	15.998	53.228**	51.992**	52.659**	89.391**	9.495
6	Spike length (cm)	3.796**	0.490*	0.609	0.423	2.350**	0.314
7	Number of spikelets per spike	4.967*	2.075	1.008	2.29 *	2.173	1.468
8	Number of grains per spike	61.642**	35.538**	52.893**	29.121**	161.700**	9.636
9	1000 grain weight (g)	3.066	44.151**	32.760**	47.371**	5.011	6.001
10	Biological yield per plant (g)	44.742	389.995**	537.884**	318.638**	2198.677**	51.704
11	Grain yield per plant (g)	5.097**	6.035**	7.867**	5.796**	0.066	0.961
12	Harvest index (%)	7.255	6.404**	5.737	6.661**	1.094	2.971

Commercial hybrid seed production is not feasible in self-pollinated crops such as wheat because of various limitations, including inadequate mechanisms to produce hybrid seed, absence of stable male sterile lines, high yielding and effective restorers, free pollen dispersal and high seed rate. Because of this, it is essential to examine heterotic combinations in terms of yield, its constituents, and quality features in the first filial generation (F_1). The superiority of hybrids, especially over better parent is more valuable for commercial exploitation of heterosis, according to Singh *et al.* (2004). They also identified the parental combinations that can produce the largest level of transgressive segregants. In the present investigation, for the majority of the characters, there was a significant range of heterosis, number of desirable hybrids and best hybrid (Table 2). The characteristics of wheat including early flowering, early maturity and small stature are desirable. Out of 45 crosses, during days to 75% heading, 2 crosses showed significant negative relative heterosis, 15 crosses showed significant negative heterobeltiosis and 13 and 26 crosses showed significant negative standard heterosis across CP1 and CP2 respectively. CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/…×UP 2901 displayed the largest negative standard heterosis over the checks. Only VORB/SOKOLL×QLD 65 demonstrated negative significant relative heterosis and 3 crosses displayed significant negative heterobeltiosis for days to maturity among all crosses. The largest negative significant standard heterosis over the two checks was seen in CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/...×UP 2901. According to the estimates of heterosis for plant height, a total of 7 and 10 crosses showed negative significant relative heterosis and heterobeltiosis, respectively. Also, significant negative standard heterosis was seen between the cross of HD 3234 and QLD 73 compared to both check parents. Short heighted varieties showing the significance of negative heterosis and heterobeltiosis for plant height due to increased lodging resistance and fertilizer responsiveness are preferred in plant breeding programmes as reported by Devi *et al.* (2013), Kumar and Kerkhi (2014), Kalhoro *et al.* (2015), and Madhukar *et al.* (2018) in their investigation for heterosis estimation in wheat and other related crops.The leaf and its associated characteristics are essential to the plant's survival under both ideal and insufficient moisture conditions. The expansion of the wheat flag leaf area is crucial for good yield production. Given that flag leaves play a major role in the synthesis of photosynthates, which are eventually translocated to grain, a number of wheat researchers came to the conclusion that positive heterosis for flag leaf area can ultimately result in increased grain output (Jatoi *et al.,* 2014). In the present investigation, 16 crosses showed positive relative heterosis significance and 9 crosses showed positive heterobeltiosis significance for flag leaf area. The highest positive significant heterosis over both mid and better parent was found in QLD 73×QLD 65. In UP 2762×UP 2901, the highest positive standard heterosis was found. This study's findings concur with those of Roy *et al.* (2021) and

Table 2: Heterosis range, number of desirable hybrids and best hybrid [over mid parent, better parent, CP1 (HD 3086) and CP2 (UP 2628)] for 12 traits in wheat

Trait	Heterosis hybrids	Heterosis range (%)	No. of desired hybrids	Best hybrids
Days to 75 % heading	MP	-2.21 to 2.77	2	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × QLD 65
	BP	-3.58 to 1.45	15	HD 3234 × UP 2901
	CP1	-3.64 to 1.45	13	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
	CP2	-5.36 to -0.36	26	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
Days to maturity	MP	-2.26 to 3.27	1	VORB/SOKOLL × QLD 65
	BP	-3.47 to 2.50	3	VORB/SOKOLL × QLD 65
	CP1	-4.89 to 0.24	34	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
	CP2	-5.12 to 0.00	36	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2901
Flag leaf area (cm^2)	MP	-21.07 to 39.02	16	QLD 73 × QLD 65
	BP	-23.09 to 34.91	9	QLD 73 × QLD 65
	CP1	4.53 to 66.79	36	HUW 640 × QLD 65
	CP2	-5.68 to 57.90	25	UP 2762 × UP 2901
Number of productive tillers per plant	MP	-29.43 to 109.68	26	UP 2901 × QLD 73
	BP	-35.73 to 94.99	20	UP 2901 × QLD 73
	CP1	-52.96 to 9.77	1	HUW 640 × VORB/SOKOLL
	CP2	-53.13 to 9.38	1	HUW 640 × VORB/SOKOLL
Plant height (cm)	MP	-8.75 to 12.33	7	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/…× VORB/SOKOLL
	BP	-12.33 to 8.17	10	HUW 640 × VORB/SOKOLL
	CP1	-6.23 to 13.81	2	HD 3234 × QLD 73
	CP2	-1.19 to 19.93	2	HD 3234 × QLD 73
Spike length (cm)	MP	-7.61 to 10.96	4	HD 3234 × UP 2762
	BP	-10.65 to 8.82	1	HD 3234 × UP 2762
	CP1	1.34 to 17.08	27	HD 3234 × UP 2762
	CP2	-7.76 to 6.56	21	HD 3234 × UP 2762
No. of spikelet/ spike	MP	-5.56 to 12.17	4	HUW 640 × VORB/SOKOLL
	BP	-7.28 to 11.49	2	HUW 640 × DBW 189
	CP1	4.21 to 22.90	25	HUW 640 × DBW 189
	CP2	-4.41 to 12.73	3	HUW 640 × DBW 189
Number of grains per spike	MP	-10.62 to 11.29	15	VORB/SOKOLL × QLD 65
	BP	-16.97 to 10.38	6	PBW 692 × VORB/SOKOLL
	CP1	-13.88 to 2.39	7	UP 2762 × QLD 73
	CP2	-13.88 to 2.39	7	UP 2762 × QLD 73
1000 grain weight (g)	MP	-16.42 to 18.29	8	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × QLD 65
	BP	-21.28 to 10.79	3	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	CP1	-11.43 to 26.53	23	VORB/SOKOLL × QLD 73
	CP2	-20.22 to 13.97	7	VORB/SOKOLL × QLD 73
Biological yield per plant (g)	MP	-24.34 to 16.81	4	VORB/SOKOLL × QLD 65
	BP	-29.25 to 8.01	2	HD 3234 × PBW 692
	CP1	-12.45 to 35.42	12	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP2	-18.51 to 26.04	7	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
Grain yield per plant (g)	MP	-21.35 to 19.47	13	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	BP	-26.22 to 14.86	5	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP1	-11.67 to 26.94	19	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
	CP2	-12.51 to 25.73	17	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × PBW 692
Harvest index (%)	MP	-12.68 to 35.76	14	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	BP	-15.18 to 34.73	5	CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5/2*KAU2/6/… × UP 2762
	CP1	-15.68 to 24.38	6	VORB/SOKOLL × QLD 73
	CP2	-15.43 to 24.74	8	VORB/SOKOLL × QLD 73

MP = average value of mid parent, BP = average value of better parent, CP1 = average value of check parent 1, CP2 = average value of check parent 2

Panwar *et al.* (2022) showing the importance of significant positive heterosis and heterobeltiosis for flag leaf area. In plant breeding, a variety with many productive tillers is preferred since they directly correlate with better grain yields per plant. The data also showed that a total of 26 and 20 crosses, respectively, showed positive significance over mid and better parent. High significant positive relative heterosis and heterobeltiosis were seen in UP 2901×QLD 73, whereas positive standard heterosis was present in HUW 640×VORB/SOKOLL. Garg *et al.* (2015), Ahmad *et al.* (2016) and Hei *et al.* (2016) also reported positive significant heterosis among their crosses revealing the role of high productive tillers directly correlate with better grain yields per plant. Increased spike length, spikelets per spike, grains per spike and 1000 grain weight are desired for the production of high yielding enhanced cultivars as these are significant yield contributing features.

Over the two assessments for spike length, HD 3234×UP 2762 showed the highest positive significant relative heterosis, heterobeltiosis and standard heterosis. Four crosses demonstrated significant positive relative heterosis, with HUW 640×VORB/SOKOLL showing the highest significant positive relative heterosis as per the estimates of heterosis for the number of spikelets per spike. Over the course of the examination, the highest positive significant heterobeltiosis and standard heterosis were found in HUW 640×DBW 189. From the estimates of heterosis for the number of grains per spike, it was further deduced that a total of 15 and 6 crosses, respectively, showed positive significant relative heterosis and heterobeltiosis. Positive estimations of standard heterosis were seen over both checks for UP 2762×QLD 73. Out of 45 crosses for 1000 grain weight, 8 and 3 crosses respectively recorded positive significance for relative heterosis and heterobeltiosis. Positive estimations of standard heterosis were seen over both inspections in VORB/SOKOLL×QLD 73. Additionally documented for the aforementioned traits are positive relative heterosis, heterobeltiosis, and standard heterosis by Baloch *et al.* (2016), Pesaraklu *et al.* (2016), and Choudhary *et al.* (2022).Grain yield is the trait of economic importance in wheat for which positive significant relative heterosis and heterobeltiosis were exhibited by 13 and 5 crosses respectively. CAL/NH//H567.71/3/SER1/4/ CAL/NH//H567.71/ 5/2*KAU2/6/…×PBW 692 performed well, demonstrating the highest positive significant relative heterosis, heterobeltiosis and standard heterosis for grain yield per plant. For biological yield per plant, this cross also showed the highest positive significant standard heterosis for both check parents.The recovery of excellent recombinants with high grain production per plant can therefore be advanced as also investigated by Singh *et al.* (2012), Ram and Shekhawat (2017), Rajput and Kandalkar (2018), and Roy *et al.* (2021)suggesting the importance of positive significance for biological and grain yield per plant. According to the analysis of estimates of heterosis for the harvest index, 14 and 5 crosses, respectively, showed positive significant relative heterosis and heterobeltiosis. The crosses between CAL/NH//H567.71/3/SER1/4/CAL/NH//H567.71/5 /2*KAU2/6/…×UP 2762 displayed the highest significant relative heterosis and heterobeltiosis while cross VORB/SOKOLL × QLD 73 showed highest positive significant standard heterosis. These hybrids can therefore be employed in breeding programs to produce plants with high harvest indices. Given that it denotes a large economic yield, a higher harvest index is a desired attribute. Dedaniya *et al.* (2018) and Panwar *et al.* (2022) have also reported significant positive heterosis for this trait.

Conclusion

Given that the parental genotypes exhibit substantial genetic diversity, there is a great deal of opportunity to use these genotypes in heterosis to improve grain yield and yield qualities. The level and extent of heterosis over the better parent, mid parent and standard check varied from cross to cross for each character. As a result, it was demonstrated that mean heterosis and its range in favoured direction varied significantly for each character. The considerable amount of high heterosis in certain crosses and low heterosis in other crosses indicates that the type of gene action varied depending on the genetic makeup of the parents involved in crossings. In order to identify the optimal cross combinations that would result in the best transgressive segregants, it would be helpful to know the type and level of heterosis. The cross between CAL/NH//H567.71/3/SER1/4/CAL/ NH//H567.71/5/2*KAU2/6/×PBW 692 shown positive significant relative heterosis, hetero beltiosis and standard heterosis in terms of grain yield per plant. In the future, breeding efforts may employ this hybrid to find excellent transgressive segregants from prior generations for grain yield enrichment.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Comparative analysis of phytoplankton dynamics and water quality assessment in selected lentic water bodies of Haryana, India

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ABSTRACT

The study was designed to assess the water quality based on physico-chemical parameters and phytoplankton communities of eight lentic water bodies of Haryana which are famous for mass bathing and religious rituals taking place here. To evaluate comparative analysis of composition, diversity and distribution of Phytoplankton and physico-chemical factors, water samples were collected seasonally viz., summer, monsoon, post monsoon and in winters from all the eight sites in triplicate. Total 118 phytoplankton taxa were observed at all sites. Among these cyanophyceae group was found most dominant at sites 1, 2, 4, 5, 7, 8 whereas cholorophyceae at site 6, bacillariophyceae at site 1,3,4,7 whereas xanthophyceae was in abundance at site 5. Population density (nos. L^{-1}) wise phytoplankton trend was Cyanophyceae > Chlorophyceae > Bacillariophyceae >Desmidiaceae and Species diversity wise phytoplankton trend observed was Chlorophyceae > Bacillariophyceae > Cyanophyceae >Desmidiaceae. Correlation of different phytoplankton groups with physicochemical factors revealed a significant negative correlation of Cyanophyceae with pH, whereas a significant positive correlation of ortho-phosphate with Desmids and bacillariophyceae wheareas CO_2 showed a positive correlation with Xanthophyceae. Appearance of pollution tolerant taxa of phytoplankton *Microcystis aeruginosa*, *Phormidium* sp., *Scenedesmus* spp., *Pediastrum* spp., *Mougeotia* sp., *Synedra* sp., *Pediastrum* spp. at most of the sites indicated the sign of the more organic pollution and degradation in the water quality of the selected sites due to religious immersion, mass bathing and by other anthropogenic activities. Suitable remedial actions should be adopted by regulatory bodies and policy makers to maintain the water quality of these aquatic systems.

Introduction

Assessment of quality of water of any aquatic ecosystem is mainly assessed by its physicochemical and biological characteristics which usually fluctuate with season and degree of pollution. Any variation in physicochemical factors of waters directly or indirectly affects its aquatic organisms. Among aquatic organisms phytoplankton have proved to be good bioindicators of water quality (Meng et al. 2017; Nguyen and Nhien 2020). They are the primary producers that biosynthesize organic material for most of the aquatic lives like zooplankton, larvae, crustaceans, fish and indirectly also for human beings functioning as a basic link in aquatic food web structure (Van de Waal and Litchman, 2020). The Phytoplankton abundance, their composition and growth are mainly affected by the physical and chemical variables of the water bodies in which they are located (Vajravelu *et al.*, 2018). Phytoplankton respond very quickly to the surrounding environment so acts as crucial biomarkers and are sensitive indicator for determining water quality status (Li *et al.*, 2019, Akhter and Brraich 2020). So, distribution patterns of phytoplankton are strongly correlated with environmental factors (Lepisto *et al.*, 2004) and

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gives insight view on interactions between biotic and abiotic factors (Kumari *et al.*, 2018). Several studies were conducted on physico-chemical parameters and phytoplankton community of water bodies such as on stream of Garhwal Himalayas (Sharma *et al*., 2016), Sulur lake of Coimbatore, South India (Manickam *et al*., 2017), water bodies of Vinh Long province, Vietnam (Trang *et al*., 2019), Coastal Water of Kudat, Sabah, Malaysia (Romin *et al*., 2021), Warna and Pengilon Lakes, Dieng, Central Java (Soeprobowati *et al*., 2021).

The knowledge of phytoplankton diversity, community structure, distribution is essential for assessing the health of any aquatic ecosystem as they are the primary biotic community that indicates changes in ecological water quality due to their sensitivity and dynamic responses to the surrounding environment (Suseela, 2009). However, no such study has been conducted so far on the selected lentic water bodies of Haryana, which are under the influence of anthropogenic activities like mass bathing and other religious rituals activities, which increases organic matter load in the waters and might be responsible for eutrophication and further algal blooms. Therefore, the present study was aimed to investigate the ecological status of the eight water bodies of Haryana on the basis of their phytoplankton composition, diversity, distribution in different seasons *viz.*, Summer, Monsoon, Post monsoon and Winter and their interrelationship with physico-chemical variables for deep understanding of water quality status of the aqua systems over time to time, this study might provide a valuable baseline data for ecological management strategies for preservation of these fragile habitat.

Material and Methods

Study area: The research area selected for study was eight lentic water bodies of Haryana State (India) situated in four districts of Haryana i.e. Yamunanagar, Kurukshetra, Kaithal and Jind shown in Table 1and Figure 1.

Sample Collection: For the collection of surface water samples, three stations were selected at each of the eight sites and samples were collected seasonally during Summer, Monsoon, Post monsoon and Winter season. 50 L water was filtered through mesh size 50 µm in collecting tube and made up to a standard volume of 40 ml, preserved for analysis of plankton. The physico-chemical characteristics were analyzed according to standard procedures of APHA (2005).

Table 1: Details of sites selected

	Name of water body	District	Latitude, Longitude
1.	Site 1(Kapalmochan)	Yamunanagar	30^0 326' N, 77^0 317' E
2.	Site 2 (Kulotarantirth)	Kurukshetra	29^0 922' N, 76^0 806' E
3.	Site 3(Bangangatirth)	Kurukshetra	29^0 937' N, 76^0 813' E
4.	Site 4 (Brahmsarovar)	Kurukshetra	29^0 961'N, 76^0 827' E
5.	Site 5 (Jyotisar)	Kurukshetra	29^0 956' N, 76^0 778' E
6.	Site 6 (Saraswati tirth)	Pehowa, Kurukshetra	29^0 978' N, 76^0 596' E
7.	Site 7 (Phalgu tirth)	Kaithal	29^0 835' N, 76^0 587' E
8.	Site 8 (Pindara tirth)	Jind	29^0 309' N, 76^0 322' E

Plankton Identification and quantification

The number of plankton to genus level was studied and identified, using the keys from Needham and Needham (1975); Tonapi (1980) and APHA (2005). Plankton abundance was expressed as plankton per liter (nos. L^{-1}) using formula:-

$$L^{-1} = \frac{(P \times C \times 100)}{L}$$

P = Number of plankton counted in ten fields, C = Volume of final concentrate of sample (i.e. 40 ml) and L = Volume of water sample filtered

Statistical analysis of data of phytoplankton composition and physicochemical parameters were analyzed and significant differences between were calculated using T test while season wise and site wise comparison of data was done using Duncan’s Multiple Range test (Duncan, 1955).

Results and Discussion

Physico-chemical characteristics (Table 2): Mean Water temperature ranged from 22.75^{0}C to 25.82^{0}C that is favorable for the optimum growth of phytoplankton (Dao & Bui, 2016). pH ranged from 7.01 to 7.48 and according to Lantang and Pakidi (2015) the ideal pH for the growth of phytoplankton in the waters is 6.5 – 8.0 so it indicates good water quality of all the sites.

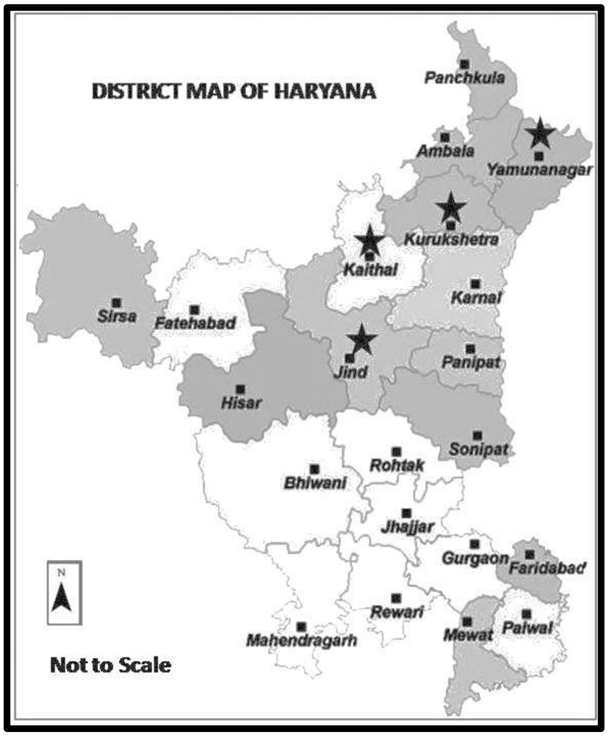

Figure 1: Map of Haryana showing the districts (★) covered under study

Conductivity ranged from 157.23 to 924.74 µ mhos cm^{-1}. The conductivity was below 500 µ mhos cm^{-1} at sites 1, 3, 4, 5 and 8 whereas at sites 2, 6 and 7 values were above 500, values above 500 µ mhos cm^{-1} indicate water was not suitable for fish and other macro-invertebtares (Mondal *et al.* 2012). Total Dissolved Solids (TDS) at sites 4, 5 and 8 have concentration less than 500 mg/Lwhile others were having the values beyond 500 mg/L. High total solids decrease the light penetration so may affect water quality indirectly and cause imbalance in aquatic life (Pawale, 2014). High turbidity and TDS might favour the growth of Cyanophyceae (Harsha and Malammanavar, 2004). Turbidity ranged from 5.14 to 43.09 NTU. According to World Health Organization (2003) the highest desirable limit is 5.0 NTU and maximum permissible limit 25.0 NTU. All the values of turbidity were within the maximum permissible limits except at sites 2. The free CO_2 which comes from microbial decomposition and by respiration activity of organisms is a vital factor for algal growth, as it is required for the process of photosynthesis. Free CO_2 ranged from 1.34 to 37.04 mg/L. High value of the free carbon dioxide content i.e. 37.04 mg/L at site 2 and 30.0 mg/L at site 8 is an indication of high degree of pollution. Dissolved Oxygen (DO) ranged from 7.14 to 10.48 mg/L. High photosynthetic rate of phytoplankton may results in higher values of dissolved oxygen (Ravindra *et al*., 2003). The obtained DO concentration satisfied the minimum recommended standard (5 ppm) set by EPA Redbook and others (USEPA 2008, Yajurvedi, 2008). As all the sites were having DO values more than 5 mg/L were found suitable for fishing and growth of planktons and was a good indication of a highly productive nature of water body (Das, 2000). Alkaline water promotes high primary productivity (Jana *et al*., 2006, Kumar and Prabhahar, 2012). Jhingram, (1982) stated that high productive water body has alkalinity over 100 mg/L and according to Yulfiperinus (2004) good alkalinity value for living organisms ranges from 100-150 ppm. During the present research most of the sites were having alkalinity more than 100 mg/L indicating their productive status and were good for the growth of phytoplankton except at site 4 and 8 where the mean values were reported lower may be due to change of water every year in December on the eve of “Geeta Jayanti”. Chloride concentration fluctuated between 6.63 to 97.7 mg/L. High chloride at site 2 indicated the presence of high organic matter, hence degree of pollution of animal origin. Total hardness was between 73.34 to 266.67 mg/L. The total hardness values were observed more than the prescribed standard (100 mg/L) of World Health Organization (WHO) except at site 4. It may be attributed to the increased mobilization of hardness causing elements like Calcium and Magnesium to be released from the subsurface ground waters having higher hardness (Badrakh *et al*., 2008). Ortho-Phosphate (o-PO_4) is the most significant nutrient responsible for eutrophication of waters. In present study, o-Phosphate varied from 0.25 to 2.85 mg/L. The higher values may be due to throwing of ashes, bathing and washing activities using soaps and detergents by the pilgrims. Davies *et al*. (2009), Sharma and Walia

Table 2: Mean (± Standard error) values of physico-chemical characteristics of waters at all the selected sites
All values are Mean ± S.E of mean

S N	Parameter	(Site 1)	(Site 2)	(Site 3)	(Site 4)	(Site 5)	(Site 6)	(Site 7)	(Site 8)
1	Temperature (^{0}C)	22.75±5.36^{A}	25.82±4.72^{A}	23.90±4.21^{A}	23.84±4.23^{A}	23.88±4.14^{A}	25.82±4.72^{A}	25.58±4.07	22.79±3.09
2	pH	7.15±0.10^{A}	7.21±0.12^{A}	7.17±0.12^{A}	7.10±0.18^{A}	7.48±0.31^{A}	7.01±0.16^{A}	7.01±0.14^{A}	7.03±0.13^{A}
3	Conductivity (µ mhos/cm)	413.50±54.18^{DE}	924.74±119.07^{A}	496.50±24.83^{CD}	157.23±4.74^{F}	284.31±36.02^{EF}	656.24±28.46^{B}	620.67±19.66^{BC}	345.42±81.32^{DE}
4	TDS (mg L^{-1})	585.59±34.15^{C}	1207.85±167.76^{A}	602.57±25.86^{C}	200.59±4.28^{D}	368.21±43.91^{D}	850.97±39.97^{B}	802.39±36.29^{B}	376.20±82.64^{D}
5	Turbidity (NTU)	10.50±4.01^{B}	43.09±16.10^{A}	7.55±2.42^{B}	6.58±2.43^{B}	5.14±1.88^{B}	9.63±2.49^{B}	20.43±8.51^{B}	9.14±2.14^{B}
6	Free CO_2 (mg/L)	8.22±4.63^{BC}	37.04±18.58^{A}	10.67±2.84^{BC}	1.34±0.55^{C}	6.83±3.98^{BC}	29.72±5.42^{AB}	4.00±2.40^{C}	30.00±13.40^{AB}
7	DO mg/L)	9.07±0.74^{A}	7.14±0.50^{A}	10.18±1.58^{A}	8.14±0.38^{A}	9.17±0.71^{A}	8.18±1.75^{A}	10.48±1.51^{A}	8.24±0.41^{A}
8	T. alkalinity (mg/L)	165.78±6.89^{C}	264.52±29.36^{A}	178.06±3.52^{BC}	34.73±1.21^{E}	100.28±11.00^{D}	179.39±7.80^{BC}	204.67±2.83^{B}	79.39±8.74^{D}
9	Chloride mg/L)	31.40±1.38^{CD}	97.70±14.47^{A}	37.36±2.19^{CD}	6.63±0.57^{F}	10.16±0.42^{EF}	74.99±5.88^{B}	42.27±3.38^{C}	24.47±8.14^{DE}
10	Hardness (mg/L)	190.89±21.88^{B}	140.59±40.05^{BC}	180.31±14.29^{B}	73.34±4.99^{C}	127.33±16.90^{BC}	266.67±17.52^{A}	185.22±38.98^{B}	100.78±8.62^{C}
11	o^- Phosphate (mg/L)	0.25±0.09^{B}	2.85±1.12^{A}	0.35±0.05^{B}	0.40±0.10^{B}	0.25±0.11^{B}	0.79±0.12^{B}	1.20±0.39^{B}	0.61±0.12^{B}
12	Ammonia (mg/L)	0.69±0.15^{AB}	1.14±0.37^{AB}	0.82±0.29^{AB}	0.31±0.13^{B}	1.19±0.85^{AB}	0.81±0.13^{AB}	1.89±0.83^{A}	0.44±0.05^{AB}

Means with different capital letters in the same row are significantly ($p<0.05$) different (Duncan's Multiple Range test). The capital letter is denoting the site wise comparison of all sites.

Table 3: Season wise distribution of total phytoplankton population (nos. L^{-1}) at all the selected sites

Site	Summer	Monsoon	Post Monsoon	Winter
Site 1 (Kapalmochan)	10480± 160Cb	9360± 160Ac	10720± 80EFb	11600±80Ea
Site 2 (Kulotarantirth)	7360±800DEa	4760± 120Db	8880± 480Fa	
Site 3 (Bangangatirth)	6280± 40Eb	6200± 120Cb	28080± 80Ca	27760± 240Ba
Site 4 (Brahmsarovar)	6600 ± 200Ec	5840±160Cc	25560± 440Da	17680± 160Db
Site 5 (Jyotisar)	37480± 40Aa	7560±280Bc	23880±120Bb	10920±200Ec
Site 6 (Saraswati tirth)	10920± 200Cb	2640± 400Ec	12680± 440Eb	36160± 1120Aa
Site 7 (Phalgu tirth)	7920± 400Dc	7400± 520Bc	42200± 1720Aa	19960± 1000Cb
Site 8 (Pandu-Pindara tirth)	23960±120Ba	9440±240Ab	10000± 80Fb	9640±200Eb

Table 4: Coefficient of Correlation between Phytoplanktons and Physico-chemical variables

SN	Phyoplankton	Abiotic factor	r value variable
1	Xanthophyceae	CO_2	0.427(*)
2	Desmidiaceae	Ortho-phosphate	0.568(**)
3	Cyanophyceae	pH	-0.424(*)
5	Desmidiaceae	Bacillariophyceae	0.505(**)
6	Total Plankton	Total Phytoplankton	0.844(**)

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

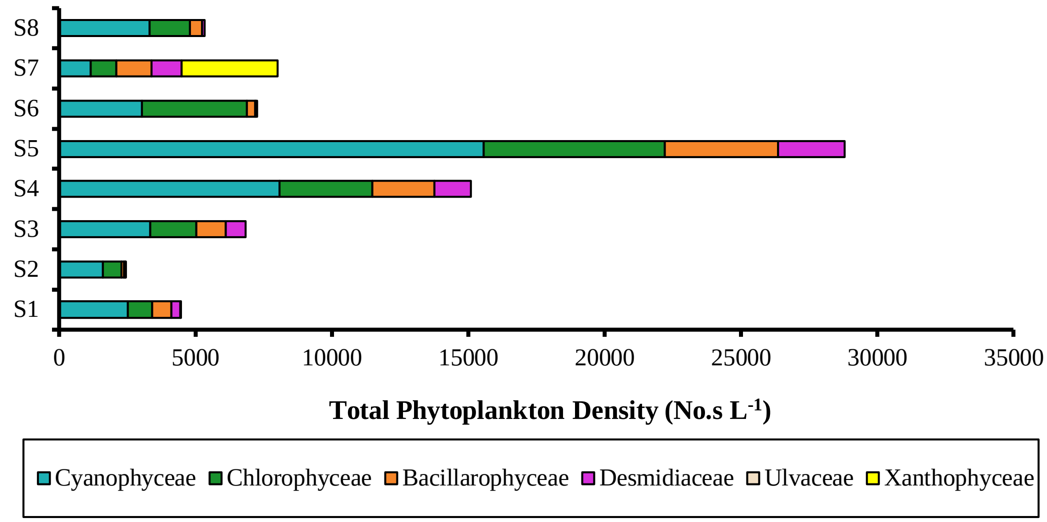

Figure 2: Total Population Density of different Phytoplankton groups at all the investigated sites

(2017) also reported increase in values of o-Phosphate due to fertilizers, soaps, detergents, and domestic sewage. However, according to Jhingram (1982) o-Phosphate content of more than 0.2 mg/L indicate productive nature of water and in the present studies it was higher than 0.2 mg/L indicating eutrophic nature of the sites. However, according to Permatasari (2016) the optimal value of orthophosphate for phytoplankton growth ranges from 0.09 to 1.80 mg/l. Ammonia ranged from 0.31 to 1.89 mg/L. Ammonia levels greater than approximately 0.1 mg/L usually indicates polluted waters and during present study mean values of ammonia were found higher than 0.1 mg/L at all the sites indicating that these sites need attention for the improvement of the water quality. Dumping of domestic and organic waste and the activities like bathing, adding ashes may be responsible for this increased ammonia concentration.The phytoplankton population ranged from 2640 to 42200 nos. L^{-1} and were found abundant at sites 2, 3, 4 and 7 during the post monsoon season, at site 5 and 8 during summer season whereas at sites 1 and 6 phytoplankton were in abundance during the winter season (Table 3). Abundance of phytoplankton during winter season is consistent with the findings of Sharma *et al.* (2016). Phytoplankton abundance during winter may be due to low water velocity, high dissolved oxygen and utilization of nutrients. A total of 118 phytoplankton species were recorded from all the eight sites and. Of these, 26 taxa belonged to Cyanophyceae, 42 taxa to Chlorophyceae, 33 taxa to Bacillarophyceae, 14 taxa to Desmidiaceae and one taxa to Xanthophyceae, Rhodophyceae, and Dinophyceae each. Amongst these, Cyanophyceae was the dominant group followed by Chlorophyceae, Bacillarophyceae and Desmidiaceae at sites 1, 2, 3, 4, 5 and site 8 that confirms the findings of Ansari *et al.* (2008) and Trang *et al.* (2019) whereas, the trend at site 6 was Chlorophyceae >Cyanohyceae>Baccilarophyceae (Figure 2). Cyanophyceae was observed in abundance at site 1, 2, 5 and 8 during summer season (Figure 4) similar to the findings of Tiwari and Chauhan (2006), Dembowska (2021) and Zhu *et al.* (2021). High temperature, extremely low water flow and high rate of evaporation might favour the growth of Cyanobacteria during summer season. Cyanophyceae was recorded maximum (65%) at site 2, followed by at site 4, 8 (62%) then at site 1 (57%), at site 5 (52%) and least was observed at site 6 (i.e. 42%) (Figure 3). Abundance of cyanophyceae at sites 6 and 7 during monsoon season consistent with the findings of Tran *et al.* (2022) (Figure 4). Cyanophyceae abundance at most of the sites indicates high pollution load and nutrient rich condition of the selected sites (Muhammad *et al*., 2005; Tas and Gonulol, 2007). Cyanophyceae revealed a significant negative correlation with pH ($r= -0.424$, $p < 0.05$) (Table 4). *Phormidium*, *Coccochloris* sp. (at site 1), *Rivularia* sp. (at site 5), *Aphanocapsa* sp. (at site 8) were abundant during the summer season (Table 5).

Table 5: Seasonal dominance of different phytoplankton taxa at all the selected sites

	Summer	Monsoon	Post Monsoon	Winter
(Site 1)	*Mougeotia, Oscillatoria*	*Mougeotia, Desmids, Diatoms*	*Mougeotia*	*Bacillarophyceae Phormidium*
(Site 2)	*Phormidium*	*Euglena, Oscillatoria*	*Microcystis, Characium, Oscillatoria, Melosira*	-
(Site 3)	*Oscillatoria, Nannochloris*	*Microcystis, Botryococcus, Oscillatoria*	*Docidium (Desmid), Oscillatoria, Ulva* sp.*, Microcystis*	*Bacillarophyceae Oscillatoria, Ulothrix*
(Site 4)	*Spirogyra, Zygnema*	*Mougeotia*	*Microcystis*	*Characium Bacillarophyceae bloom*
(Site 5)	*Rivularia, Zygnema, Mougeotia, Rhoplalodia, Syneccococcus*	*Cymbella, Microspora, Phormidium*	*Microcystis, Stichococcus, Coelastrum, Phormidium, Oscillatoria*	*Zygnema, Synedra*
(Site 6)	*Oscillatoria, Pediastrum, Nannochloris*	*Oscillatoria*	*Oscillatoria, Nannochloris, Microcystis*	*Cladophora, Phormidium*
(Site 7)	*Microcystis aeruginosa*	*Microcystis*	*Pediastrum, Tribonema*	*Closterium juncidum*
(Site 8)	*Oscillatoria, Microcystis, Aphanocapsa, Enteromorpha*	*Microcystis, Pediastrum duplex*	*Mougeotia , Microcystis, Cladophora, Draparnaldia*	*Oscillatoria, Bacillarophyceae*

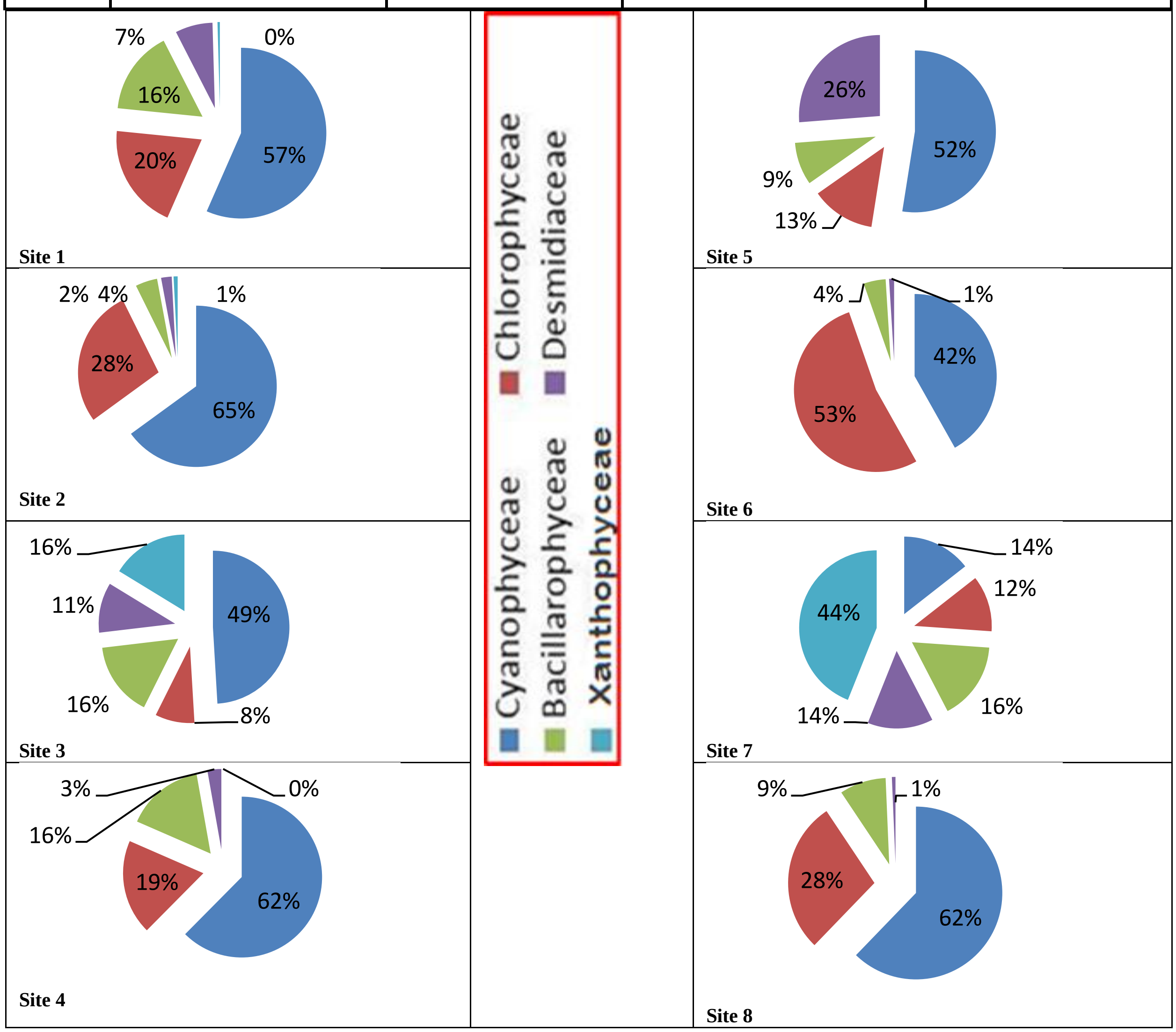

Figure 3: Per cent distribution of different groups of phytoplankton at all the sites (1-8).

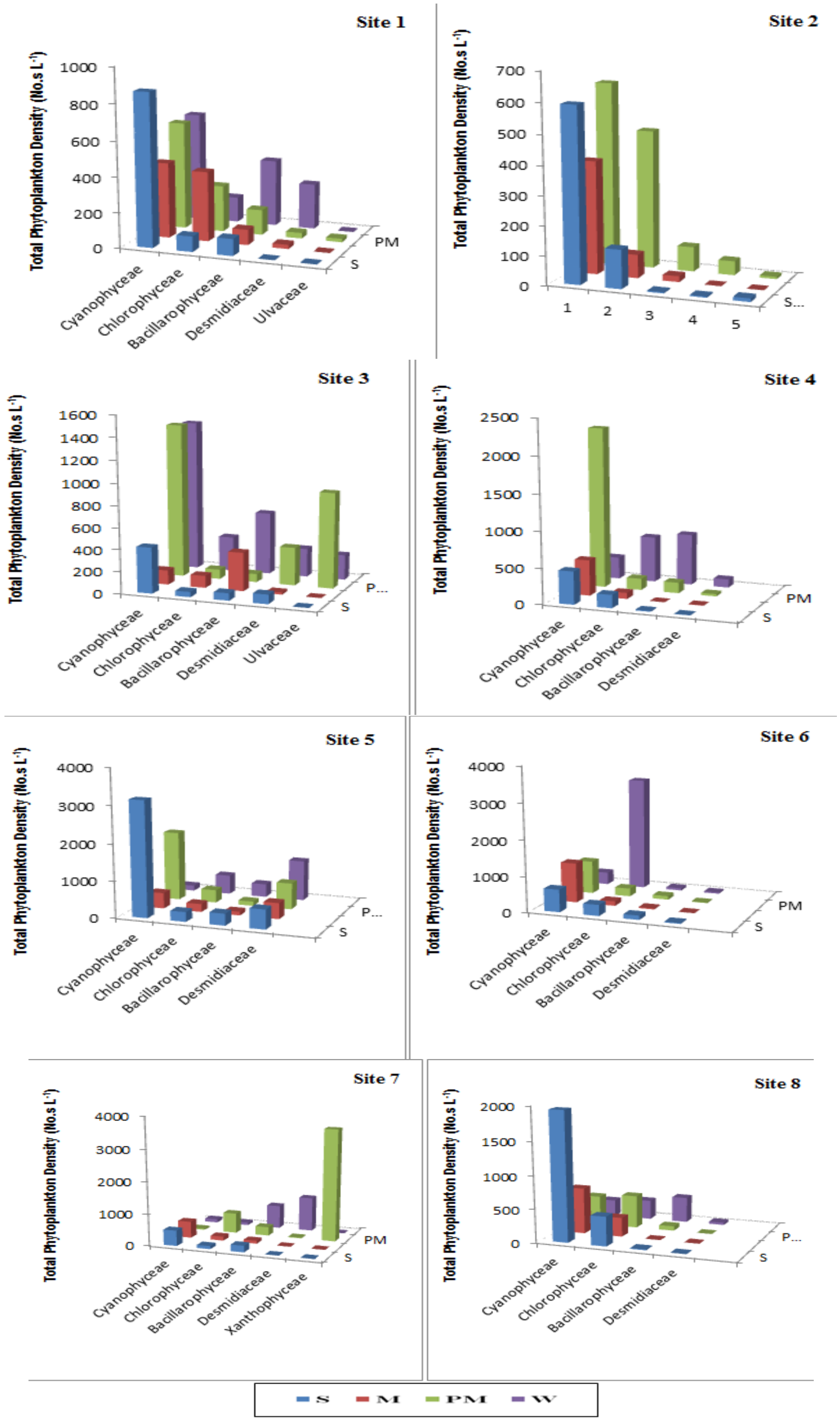

Figure 4: Seasonal distribution of different groups of phytoplankton at all the sites (1-8)

Microcystis aeruginosa was recorded in abundance at all the sites in all the seasons and forms blooms mainly in the post monsoon season except at site 1 (Table 5) indicates the eutrophic status of waterways and best indicator of pollution in water bodies (Nandan and Aher, 2005). Presence of *Rivularia* sp. (Hulyal and Kaliwal, 2009), *Oscillatoria* (Ansari *et al.*, 2008, Kumari *et al*., 2008, Rishi and Awasthi, 2012) indicates eutrophication of lake and can be regarded as 'Marker species' or indicator of water pollution. The study revealed that Cyanophyceae prefer to grow at slightly alkaline conditions that is similar to the findings of Kadhim (2014).Chlorophyceae was the dominant group at site 6 (Figure 2) i.e. 53% and least was recorded at site 3 (8%) (Figure 3). A total of 42 species were recorded from Chlorophyceae. Chlorophyceae are found in abundance in lakes having sufficient light intensity (Dembowska *et al*., 2018) and High N and P content also favors chlorophyceae (Deyab, 2002). It was found in abundance at site 3, 4, 5 and 6 during winters (Figure 4). At site 6 it was mainly represented by the *Cladophora* sp. in winter and *Nannochloris* sp. in post monsoon season (Table 5). *Scenedesmus* spp., *Pediastrum* spp. and *Mougeotia* sp. were reported at all the sites. Scenedesmus spp., *Pediastrum* spp., *Cosmarium, Ulva* sp. abundance may indicates eutrophic waters and also indicates that sewage pollution of waters reservoirs (Rogers, 2003, Kumari *et al*., 2008). Sewage wastes may be added in the waters by the village people around the site. *Pediastrum duplex, Ulothrix* sp., *Cladophora* sp., *Coelastrum* sp. and *Ulva* sp. were regarded as pollution tolerant taxa in present study. Abundance of *Ulothrix sp*. in winters at site 3 and abundance of *Coelastrum* and *Zygnema* sp. at site 5 during post monsoon period and winter period respectively (Table 5) indicates pollution of water at these sites is consistent with the findings of Rai *et al*. (2008) and Hulyal and Kaliwal (2009).Diatoms are regarded as the best indicators of quality and tropic status of the water body (Callieri, 2008). Bacillariophyceae can be used as bio-indicators for water quality evaluation due to their short regeneration time and sensitive behaviour towards ecological characteristics (Goma *et al.*, 2005). Overall population density wise it was in abundance at site 5 and least at site 2 (Figure 2). Percent wise distribution revealed that it was maximum (i.e. 16%) at sites 1, 3, 4 and 7 and least (i.e. 4 %) was recorded at sites 2 and 6 (Figure 2). Members of Bacillarophyceae were in abundance during the winter season at almost all the sites (Figure 4). This dominance is similar to the findings of Tiwari and Chauhan (2006), Negi *et al.* (2012) and Sharma *et al.* (2016). Nautiyal *et al.* (2012) and Tarar and Bodhke (2002) stated that winter months were more favourable for the multiplication of diatoms. In the present results, Bacillarophyceae was represented by 33 genera. The dominant taxa observed were *Navicula* spp., *Synedra* spp., *Nitzschia* spp. that was recorded from almost all the sites. *Nitzschia, Pinnularia* regarded as indicators of organic pollution (Rai *et al.*, 2008, George *et al.*, 2012, Bhat *et al.*, 2015). *Cyclotella* sp. and *Navicula* sp. also indicated the eutrophic and polluted nature of aquatic system (Kumari *et al.*, 2008 and Shruthi *et al*., 2011). In Desmidiaceae group a total of 14 taxa were observed at sites 1-8. Population density of desmids (No.s L^{-1}) and Per cent wise distribution was found maximum at site 5 (i.e. 26%) followed by at site 7 (14%) then at site 3 (11%) (Figure 2, Figure 3). *Docidium sp.* was recorded in abundance during post monsoon period at site 1 and Site 3 whereas *Closterium juncidum* was recorded as dominant sp. during winter period and was in abundance at site 7 (Table 5). Presence of *Closterium* sp. indicated the polluted nature of the water body (Hulyal and Kaliwal, 2009). Hence site 7 can be considered as polluted in winter season. *Closterium* sp. and *Cosmarium* sp. indicated the pollution and eutrophic status of the sites 3, 7. Bacillariophyceae and Desmids were found to be positively correlated ($r= 0.505, p<0.01$) with each other (Table 4).Xanthophyceae was found to be dominant (44%) among phytoplankton at site 7 in post monsoon period followed by at site 3 (16%) (Figure 3 & Figure 4). It was mainly represented by mainly one genera i.e. *Tribonema* sp. Xanthophyceae ($r= 0.427, p<0.05$) and CO_2 also showed a positive correlation (Table 4).Season wise distribution showed that *Phormidium, Coccochloris, Syneccococcus, Rhopalodiagibba, Aphanocapsa, Nannochloris, Microcystis aeruginosa, Synedra* sp, *Aphanocapsa, Enteromorpha* taxa were common during summer season. The abundance of phytoplankton during summer may be attributed to faster microbial decomposition action making nutrient rich water with abundant food present in form of photosynthesis (Hassan *et al.*, 2010). Overall *Phormidium* sp., *Microcystis* sp., *Synedra* sp., *Spirogyra* sp., *Mougeotia*, *Scenedesmus* sp., *Pediastrum* sp., *Navicula* spp., *Nitzschia* sp. were common to all the stations and can be regarded as good indicators of water pollution. Presence of *Microcystis aeruginosa*, *Phormidium* sp., *Oscillatoria* sp., *Closterium* sp., *Synedra* sp., *Spirogyra* sp., *Ulothrix* sp., *Pediastrum* spp., *Cladophora* sp., *Synedra* spp., clearly indicated that water is polluted. Similar observation has been made by (Chandrashekar *et al.*, 2003 and by Tiwari and Chauhan, 2006).

Conclusion

Physicochemical factors analysis depicted that the sites 2, 6 and 7 were more polluted as comparison to the other sites and site 4 was found least polluted. The study of physicochemical parameters and phytoplankton were found correlated with each other as both were showing the productive and eutrophic nature of the sites. Presence of *Microcystis aeruginosa*, *Oscillatoria* sp., *Rivularia* sp., *Pediastrum* sp., *Scenedesmus*, *Spirogyra* sp., *Synedra* sp., *Navicula* spp., *Nitzschia* sp. can be used as pollution indicators species to know the ecological status of waters to meet the needs for particular assessment of water protection programs. Suitable remedial measures and social awareness campaigns should be adopted to control pollution of these aquatic systems arising from the various anthropogenic activities and mass bathing at these sites for maintaining the water quality of these ponds. Detail knowledge of identification, reproductive period, life cycle, ecological niche of phytoplankton also required for detail analysis of their response to the environment variables and effects like eutrophication, acidification, salinity, warming. Besides that, regular quantitatively and qualitatively monitoring of other water quality like nutrient and hydrodynamics profiling is indispensable to realize better management of healthy ecosystem.

Conflict of interest

The authors declare that they have no conflict of interest.

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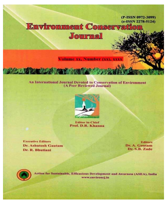

Effect of agricultural waste on nutritional composition of oyster mushroom (*Pleurotus ostreatus*)

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Substrates

ABSTRACT

The oyster mushroom (*Pleurotus ostreatus*) was cultivated on diverse substrates, encompassing wheat straw (T_1), paddy straw (T_2), groundnut leaves and straw (T_3), sugarcane bagasses (T_4), cotton stalk (T_5), coconut husk (T_6), pigeon pea straw (T_7), and banana pseudostem (T_8). The study comprised of the estimation of proximate composition, antioxidants, and mineral content of the sun-dried mushrooms during the initial two harvests. The average values of nutritional parameters were as follows: moisture (90.93 to 85.18 %), ash (7.62 to 4.86%), carbohydrates (37.57 to 20.10%), crude protein (45.45 to 23.10%), crude fiber (29.08 to 19.29%), crude fat (2.68 to 1.63%), total phenol (14.23 to 9.12 mg/g) and ascorbic acid (11.58 to 8.72 mg/100g). The average mineral content exhibited the trend K>P>Mg>Ca>Zn>Fe>Cu. Upon consideration of average values from both harvests, the groundnut leaves and straw had the highest crude protein (45.45 %), total phenol (14.23 mg/g), ascorbic acid (11.58 mg/100g), phosphorous (0.43 %), iron (7.12 mg/100g) and zinc (12.43 mg/100g). The paddy straw resulted in the highest crude fiber (29.08 %) and crude fat (2.68 %), while the wheat straw resulted in the highest potassium (1.52 %) and calcium (179.65 mg/100g). The various substrates had an impact on nutritional parameters as seen by either an increase or decrease in various parameters which can be reflected in turn by the composition of the substrates itself. In conclusion, groundnut leaves and straw (T_3) along with paddy straw (T_2) and wheat straw (T_1) resulted in significant improvement of nutritional composition compared to other treatments. This study underscores the environmentally friendly utilization of nutrients from agricultural waste for mushroom production.

Introduction

A substantial portion of the world's waste is produced by the agriculture industry. For example, the residues such as stalks, husks, molasses etc. The nutritive value of these wastes, in particular, is an interesting attribute that draws their utilization in directions that have significant positive effects on the economy and society. Because they promote the growth and development of mycelia into mushroom fruit bodies, agricultural wastes have long been regarded as a good source of nutrients for the production of mushrooms. Therefore, mushroom cultivation is the most effective and financially feasible biotechnology to solve the environment-related problems using agricultural wastes as a raw

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material. It is an interesting approach to use agricultural wastes as a bioconservation for the controlled cultivation of edible mushrooms (Wei *et al*., 2022). By using waste from the agricultural and agro-based industries as raw materials, production costs can be lowered and waste can be recycled, contributing to an eco-friendly environment (Sadh *et al*., 2018).Oyster mushrooms, also known as *Pleurotus ostreatus* (white-rot fungi), are members of the *Pleurotaceae* family. With 99% of the world's production and consumption of *P. ostreatus* mushrooms coming from Europe, Africa, and Asian countries (especially India, South Korea, China, Taiwan, Japan, Thailand, and Vietnam), it is one of the most widely cultivated mushroom species and the second-largest commercially produced mushroom after the *Agaricus bisporus* (Lesa *et al*., 2022). The total production of oyster mushroom in India during the year 2016 was 21, 272 metric tonnes. The states involved in oyster mushroom production in India are Odisha, Tamil Nadu, Maharashtra, Punjab, Bihar, West Bengal, Uttrakhand, Gujarat and Andhra Pradesh (Sharma *et al*., 2017). There are many benefits for cultivating *P. ostreatus* over other edible mushrooms. These are listed below: (1) has the potential for high yields, high nutritional value and medicinal importance; (2) grows rapidly in a broad range of temperatures (10°C to 30°C) and pH (6–8); (3) has the ability to degrade ligno-cellulosic biomass of substrates; (4) requires minimal environmental control; (5) can colonise substrates more quickly; and (6) does not require composting of its substrate. Additionally, they can frequently be grown simply and economically, and their cultivation only needs pasteurisation, which is affordable and does not require a more expensive method like sterilization. Additionally, diseases or pests do not frequently attack their fruiting bodies (Lesa *et al*., 2022).Mushrooms are highly valued for their distinctive flavour and delectability, as well as the fact that they are high in protein, low in fat, high in fibre, low in carbohydrates and sodium, and high in vitamins (thiamine, riboflavin, folic acid, and niacin), which are uncommon in vegetables. Due to their high availability of lysine, tryptophan, and other amino acids typically lacking in cereals, they are an ideal choice for patients with hypertension, diabetes, and obesity (Carel *et al*., 2013). Agricultural wastes can be effectively degraded by *Pleurotus* species which can grow in a variety of temperatures. Compared to other edible mushrooms, they need less time to grow. Carbon, nitrogen, and inorganic substances are among the nutritional sources required by *Pleurotus* species. Materials containing cellulose, hemicellulose, and lignin (such as rice and wheat straw, cotton seed hulls, sawdust, waste paper, leaves, and sugarcane residue) can be used as substrates for growing mushrooms because the main nutrients for mushrooms are more carbon and less nitrogen. Oyster mushrooms can grow on a variety of substrates, but the yield and quality of oyster mushrooms are influenced by the chemical and nutrient content of the substrates (Hoa *et al*., 2015). With this context, this study was conducted to determine the nutritional value of oyster mushrooms grown on various types of agricultural waste.

Material and Methods

The mushrooms were grown, and their nutritional composition was analyzed at the Department of Biochemistry, Junagadh Agricultural University, Junagadh, from September 2022 to March 2023.

Mushroom material and spawn preparation

The oyster mushroom was collected from the Department of Plant Pathology, Junagadh Agricultural University, Junagadh and the mother culture was maintained. Sorghum grains were used for spawn preparation and the grains were filled in autoclavable polypropylene bags and autoclaved at 121°C for 20 minutes. Around 5 g of grains from master spawn were inoculated in mother spawn bags under the laminar airflow with the help of the sterile spatula. All the bags were incubated at 28± 2°C in incubator. After few days mycelia growth cover the surface of sorghum grain and such bags were used for further experiment (Kotadiya, 2021).

Substrate preparation

Different substrates used in this experiment were T_1 Wheat straw, T_2 Paddy straw, T_3 Groundnut leaves and straw, T_4 Sugarcane bagasses, T_5 Cotton stalk, T_6 Coconut husk, T_7 Pigeonpea stalk and T_8 Banana pseudostem. The chopped substrates were soaked in water to the extent that it contains 68 to 70 % moisture. The soaked substrates were chemically treated with 40% formaldehyde solution (13.50

ml/10 litres of water) and 50% carbendazim wetable powder @10g/10 litres of water for a 24-hour period. After 24 hours, water and chemical mixture was removed. The excess solution was removed from treated substrates by placing them on a sieve for an hour. The bag was sterilized in autoclave (Kotadiya, 2021).

Mushroom bag preparation

Polythene bag was taken and kept inverted. The end of the bag was secured with a plastic thread. Then, the bags were reverted. After the substrates were compressed, it was layered into autoclavable polythene bags (60 x 30 cm, 80 gauge). Layer spawning (3%) was done at periphery of the bag between 2 layers of substrate. Strings were used to tie bags. Bags had tiny holes made for gaseous exchange and effective aeration. Bags were kept in the room where the room temperature was 20^{0}c to 25^{0}c and 80 to 90% humidity. The packed blocks or bags were incubated in a well-ventilated, dark environment until the mycelium had completely reached the substrate's base. Bricks were used to support the bags, which increased their height and kept the bags away from water and pests (Kotadiya, 2021).

Harvesting

The mature fruits were picked before their margins began to inwardly fold. The nutritional parameters were analyzed during 1^{st} and 2^{nd} picking.

Fruiting body analysis

The nutritional composition was estimated using the sun-dried mushroom powder.This dry powder was used for the analysis of ash, crude protein, crude fat, crude fiber, total phenol, carbohydrate, ascorbic acid and minerals. The standard analytical techniques were utilized to ascertain the moisture and ash content (AOAC, 2000). The crude protein, crude fat, and crude fibre were determined using the automatic digestion-distillation unit, the Soxtherm unit, and the Fibretherm extraction unit, respectively, by employing the method of AOAC (2000). The carbohydrate and total phenol content were determined spectrophotometrically, whereas the ascorbic acid content was estimated using the titration method given by Sadasivam and Manickam (2008). For estimation of minerals, the sample extraction was done by microwave digestion system. The minerals i.e. calcium, magnesium, copper, iron, and zinc in the mushroom sample were estimated using MP-AES. Potassium was determined using flame photometer whereas phosphorus content was estimated spectrophotometrically (AOAC, 2000).

Statistical analysis

The analysis of the nutritional parameters studied was done in three replications. Statistical data analysis was carried out as per Completely Randomized Design. Using the standard statistical methods outlined by Panse and Sukhatme (1985), analysis of variance was calculated.

Results and Discussion

Effect of different substrates on the nutritional composition of the fruiting body

Moisture content is one of the major constituents of fresh mushroom and it can vary depending on the substrate used (Table 1). In the first picking, the significantly least moisture content was found in cotton stalk (84.29 %) whereas in the second picking, banaana pseudostem resulted in significantly least moisture content (82.32 %). The average moisture content ranged from 90.93% in wheat straw to 85.18% banana pseudostem. Previous works of Iqbal *et al.* (2016) and Patil *et al.* (2010) had shown similar results of moisture content in oyster mushroom grown on different substrates. The age of the mushrooms, the growing conditions, the types of mushrooms used, and the postharvest conditions all had an impact on the moisture content (Hoa *et al.* 2015). The ash content during the two pickings is as shown in Table 1. During the first picking, maximum ash content was found in paddy straw (9.31%) which was at par with wheat straw (8.64 %), sugarcane bagasses (8.34 %) and banana pseudostem (8.08 %) while in the second picking maximum ash content was in coconut husk (7.84%) which was at par with groundnut leaves and straw (7.47 %) and banana pseudostem (7.17 %). The average data revealed that maximum ash content was recorded in banana pseudostem (7.62 %) while minimum ash content recorded in pigeon pea straw (4.86 %). According to a study by Patil (2012), the ash content of mushrooms varied between 5.90% and 7.00%, which is in line with the outcomes of the current experiment. The results of the experiment are is agreement with the findings of Ashraf *et al.* (2013) who found that the ash content of oyster mushroomwas recorded maximum in wheat straw (9.08 %) and minimum in cotton waste (6.76 %).

Table 1: Effect of different substrates on the nutritional composition of the fruiting body

Treatment	Moisture (%)*			Ash content (%)			Carbohydrate (%)			Crude protein (%)		
	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average
T_1	92.73	89.14	90.93	8.64	4.81	6.72	35.46	33.42	34.44	28.65	26.25	27.45
T_2	92.86	85.47	89.16	9.31	4.68	6.99	29.11	37.37	33.24	23.77	22.44	23.10
T_3	87.59	87.25	87.42	7.69	7.47	7.58	27.10	19.49	23.29	46.27	44.63	45.45
T_4	91.74	88.16	89.95	8.34	4.53	6.43	43.53	31.61	37.57	25.57	24.69	25.13
T_5	84.29	88.03	86.16	6.82	3.87	5.34	30.89	25.84	28.36	35.88	28.38	32.13
T_6	91.56	86.53	89.04	7.24	7.84	7.54	26.43	21.05	23.74	32.40	26.55	29.47
T_7	88.30	87.99	88.14	6.41	3.32	4.86	31.95	28.31	30.13	33.89	28.64	31.26
T_8	88.05	82.32	85.18	8.08	7.17	7.62	22.14	18.07	20.10	33.36	28.43	30.89
S.Em.±	0.53	0.97		0.40	0.30		0.98	1.02		0.98	0.91	
CD at 5 %	1.60	2.94		1.23	0.91		2.97	3.09		2.97	2.75	

*** fresh weight basis**

Table 2: Effect of different substrates on the nutritional composition of the fruiting body

Treatment	Crude fiber (%)			Crude fat (%)			Total phenol (mg/g)			Ascorbic acid (mg/100g)		
	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average
T_1	29.85	28.17	29.01	2.43	2.00	2.21	14.78	10.63	12.70	11.13	09.09	10.11
T_2	28.96	29.21	29.08	2.47	2.90	2.68	11.63	10.19	10.91	11.70	09.15	10.42
T_3	21.78	19.69	20.73	2.30	1.50	1.90	14.39	14.07	14.23	10.89	12.27	11.58
T_4	26.77	30.20	28.48	1.68	1.69	1.68	14.47	10.27	12.37	08.72	08.73	08.72
T_5	26.25	22.94	24.59	1.77	1.53	1.65	11.04	9.56	10.30	09.06	08.72	08.89
T_6	18.89	19.69	19.29	1.78	1.76	1.77	9.23	9.02	9.12	09.60	10.81	10.20
T_7	21.44	22.45	21.94	1.68	1.77	1.72	13.60	8.43	11.01	10.03	10.22	10.12
T_8	24.45	28.88	26.66	1.70	1.56	1.63	13.85	7.77	10.81	09.96	10.64	10.30
S.Em.±	0.56	0.83		0.03	0.03		0.23	0.23		0.33	0.31	
CD at 5 %	1.69	2.50		0.11	0.10		0.70	0.71		1.00	0.95	

T_1= Wheat Straw **T_2= paddy Straw** **T_3= Groundnut leaves and Straw**

T_4= Sugarcane Bagasses **T_5= Cotton Stalk** **T_6=Coconut Husk**

T_7= Pigeon Pea Straw **T_8= Banana Pseudo Stem**

This study shows that oyster mushroom fruiting bodies grown on all substrate types are rich in protein, carbohydrates, and fibre and have a low fat content, making them excellent foods that can be used in low-calorie diets (Hoa *et al*., 2015, Raman *et al*., 2021). The cell wall of a mushroom is typically made up of carbohydrates. The two primary polysaccharides of the cell wall are mannan and glucan. Mannan has a radio-protective effect, while glucan as food has a positive impact on lowering serum cholesterol, a risk for cardio-vascular disease (Maftoun *et al.,* 2015). In first picking, carbohydrate content was significantly higher in sugarcane bagasses (43.53 %) followed by wheat straw (35.46%). In second picking, carbohydrate content was significantly higher in paddy straw (37.37 %) compared to the other treatments (Table 1). The average data indicated that the maximum carbohydrate content was found in sugarcane bagasses (37.57 %) while the lowest carbohydrate was in banana pseudostem (20.10%). The carbohydrate content of oyster mushroom cultivated on different substrates was reported in range from 30.24 to 42.26% (Sharma *et al*., 2013; Ashraf *et al*., 2013). For vegetarians in particular, the genus *Pleurotus* can be regarded as a reliable source of palatable proteins (Raman *et al.,* 2021). The average crude protein content in mushroom harvested from different substrates ranged from 23.10 % to 45.45 % (Table 1). Irrespective of picking stages, significantly highest crude protein content (46.27 % and 44.63 %) was found in treatment T_3 (groundnut leaves and straw). The lowest crude protein content was found in treatment T_2 (paddy straw) 23.77 and 22.44% respectively which was at par with treatment T_4 (sugarcane bagasses) 25.57 and 24.69% respectively in both the pickings. Protein content of oyster mushroom grown on different substrates ranging from 22.89% to 25.97% was reported in previous studies (Sharma *et al.,* 2013; Tirkey *et al*., 2017). The varying nitrogen content of the substrates may be the cause of the difference in the protein content of the oyster mushrooms grown on various substrates (Hoa *et al*., 2015). Mushroom protein content is influenced by a number of variables, including the type and quantity of additive nutrients in the substrate, pileus size, cultivation time, and strain (Jeznabadi *et al*., 2016).

Mushrooms are excellent sources of valuable food compounds for humans and contain edible dietary fibre. Chitin and polysaccharide in the cell walls of mushrooms make up the majority of their dietary fibre (Raman *et al*., 2020). The average fibre content across all substrates showed that paddy straw produced the highest fibre content (29.08%), while coconut husk resulted in the lowest fibre content (19.29%). Based on the data from Table 2, it is evident that the fibre content was higher in wheat straw (29.85 %) which was statistically at par with paddy straw (28.96 %) in first picking. In the second picking, higher amount of fibre was found in sugarcane bagasses (30.20 %) which were at par with paddy straw (29.21%), banana pseudostem (28.88%) and wheat straw (28.17 %). The results of this study is close to the values reported by Ashraf *et al*. (2013) who found the fibre content of 26.28 % in wheat straw and 24.53 % in cotton waste from oyster mushroom. Among the different substrates used for growth of *Pleurotus ostreatus*, rice straw resulted in the highest fibre content, and the overall fibre content ranged from 12 to 14% (Sharma *et al*., 2013).

All lipids, free fatty acids, mono-, di-, and triglycerides, sterols, sterol esters, and phospholipids are included in the crude fat of edible and therapeutic mushrooms (Raman *et al.,* 2021). The average values indicated that the paddy straw resulted in the highest amount of crude fat (2.68 %) while the least amount of crude fat (1.63 %) was reported in the banana pseudostem (Table 2). In the first picking, paddy straw had the highest fat content which was at par with wheat straw (2.47 and 2.43 % respectively). Paddy straw had significantly higher fat content (2.90 %), which was followed by wheat straw (2.00 %) during the second picking. A fat content in the range of 2.46 to 2.85%; 2.28 to 2.60 % and 0.77 to 2.26% was reported in *Pleurotus sajor-caju, Pleurotus florida*, and *Pleurotus djamor* cultivated on different agro-wastes (Patil, 2012; Ahmed *et al*., 2009; Vega *et al*., 2022).

The phenolic component in *Pleurotus* species is variable and they are most related to antioxidants and phytonutrients (Raman *et al.,* 2020). Data of phenol content depicted in Table 2 demonstrates that the wheat straw resulted in the highest phenol content (14.78 mg/g) which was statistically at par with sugarcane bagasses (14.47 mg/g), and groundnut leaves and straw (14.39 mg/g) during the first picking. In the second picking, phenol content was significantly higher in groundnut leaves and straw (14.07 mg/g) than other treatments. Upon considering theaverage values, groundnut leaves and straw exhibited highest phenol content (14.23 mg/g) whereas the coconut husk resulted in the least amount of phenol (9.12 mg/g). The phenol content declined during the second picking in all the treatments. According to Mishra *et al*. (2013), the total phenol content of various oyster mushroom species ranged from 3.94 to 21.67 mg/g. Our results are consistent with their findings. The phenolic content of pink oyster mushroom grown on paddy straw ranged from 5.60 to 6.75 (mg/g) (Raman *et al*., 2020).

The average data revealed that the groundnut leaves and straw resulted in the highest amount of ascorbic acid (11.58 mg/100g), while the sugarcane bagasses resulted in the lowest amount of ascorbic acid (8.72 mg/100g) (Table 2). During the first picking, the highest amount of ascorbic acid was found in mushroom from paddy straw (11.70 mg/100g) which was statistically at par with wheat straw (11.13 mg/100g), and groundnut leaves and straw (10.89 mg/100g). In second picking, among all the treatments, the amount of ascorbic acid content was significantly higher in groundnut leaves and straw (12.27 mg/100g). Ascorbic acid (vitamin C) is a valuable food component because the vitamin content plays a significant role in the overall nutritional value of food due to its antioxidant and therapeutic properties (Adejumo *et al.,* 2015). *Pleurotus ostreatus* grown on different lignocellulosic agro-waste resulted in ascorbic acid content of 12.52 to 15.80 mg/100g (Patil *et al*., 2010).

Effect of different substrates on mineral content of fruiting body

Calcium, potassium, magnesium, phosphorus, and sodium are known to be present in mushrooms and are essential nutrients for humans. They are necessary for rebuilding blood cells, maintaining osmotic balance, strengthening bone and teeth, and repairing worn-out cells (Adejumo *et al.,* 2015). The mushroom's adsorption and accumulation of these elements from the growth substrate may account for variations in mineral compositions (Ritota and Manzi, 2019). The average data indicated that the groundnut leaves and straw had the highest amount of phosphorous content (0.43 %) while the pigeonpea straw resulted in the lowest amount of phosphorous content (0.32 %).The data presented in Table 3 depicts that in the first picking groundnut leaves and straw recorded maximum phosphorous content (0.47 %) which was at par with cotton stalk (0.46 %). In second picking, coconut husk recorded higher phosphorous content (0.43 %) which was at par with groundnut leaves and straw (0.40 %). Ponmurugan *et al*. (2007) reported similar results, stating that the range of phosphorous content of mushrooms grown on different substrates was 0.11 to 0.25%.

Potassium plays a crucial role in a variety of mechanisms, including growth, the metabolism of carbohydrates, ionic balance, enzyme activity, and the differentiation of cap and gills (Zahid *et al*., 2020). The average value of potassium content of oyster mushroom (*Pleurotus ostreatus*) ranged from 0.94 to 1.52 % (Table 3). The wheat straw recorded significantly higher potassium content compared to other treatments in both harvests. Irrespective of the treatments, there was a decline in the potassium content in the second picking. A similar range of potassium content was observed in oyster mushrooms grown on different wastes, ranging from 1.9 to 2.1% (Yehia, 2012).

Mushrooms are an important food because they contain calcium, which is necessary for bone growth and maintenance as well as for the healthy operation of muscles and nerves in both humans and other animals (Elkanah *et al*., 2022). The data shown in the Table 3 revealed that in first picking, calcium content was significantly higher in wheat straw (236.04 mg/100g) which was followed by paddy straw (227.87 mg/100g). In second picking, sugarcane bagasses recorded maximum calcium content (129.79 mg/100g) which was at par with coconut husk (129.75 mg/100g). On an average, wheat straw led to maximum calcium content (179.65 mg/100g) whereas the pigeon pea straw resulted in minimum calcium content (104.51 mg/100g). There was a decline in the calcium content during the second harvest in all the treatments. The results of a study conducted by Yehia (2012) revealed the highest calcium content

Table 3: Effect of different substrates on the mineral content of the fruiting body

Treatment	Phosphorous (%)			Potassium (%)			Calcium (mg/100g)			Magnesium (mg/100g)		
	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average
T_1	0.38	0.31	0.34	1.66	1.38	1.52	236.04	123.27	179.65	166.72	164.16	165.44
T_2	0.38	0.30	0.34	1.57	1.04	1.30	227.87	119.84	173.85	176.90	148.62	162.76
T_3	0.47	0.40	0.43	1.02	0.87	0.94	157.52	127.63	142.57	182.92	118.64	150.78
T_4	0.36	0.37	0.36	1.34	0.97	1.15	147.14	129.79	138.46	146.89	160.31	153.60
T_5	0.46	0.38	0.42	1.37	0.87	1.12	126.00	115.16	120.58	161.74	165.56	163.65
T_6	0.39	0.43	0.41	1.02	0.86	0.94	161.60	129.75	145.67	177.41	180.49	178.95
T_7	0.36	0.28	0.32	1.28	0.82	1.05	110.50	98.52	104.51	115.66	114.60	115.13
T_8	0.37	0.35	0.36	1.44	0.67	1.05	149.38	117.59	133.49	197.06	176.48	186.77
S.Em.±	0.008	0.008		0.007	0.015		0.081	0.078		0.083	0.081	
CD at 5 %	0.025	0.027		0.024	0.046		0.246	0.236		0.251	0.245	

Table 4: Effect of different substrates on the mineral content of the fruiting body

Treatment	Copper (mg/100g)			Iron (mg/100g)			Zinc (mg/100g)		
	1st picking	2nd picking	Average	1st picking	2nd picking	Average	1st picking	2nd picking	Average
T_1	1.73	1.25	1.49	6.15	4.23	5.19	10.02	8.89	9.45
T_2	1.94	1.45	1.69	6.19	5.50	5.84	8.72	7.21	7.96
T_3	3.72	1.66	2.69	8.60	5.64	7.12	13.74	11.12	12.43
T_4	1.43	1.26	1.34	4.35	2.90	3.63	8.51	6.40	7.45
T_5	1.69	1.25	1.47	3.06	3.03	3.04	8.79	7.60	8.19
T_6	1.99	1.88	1.94	3.68	3.26	3.47	9.02	7.60	8.31
T_7	7.24	5.02	6.13	4.74	3.75	4.25	7.52	7.22	7.37
T_8	2.07	1.25	1.66	5.53	5.39	5.46	7.23	4.54	5.88
S.Em.±	0.07	0.05		0.09	0.07		0.10	0.10	
CD at 5 %	0.22	0.18		0.28	0.23		0.31	0.31	

T_1= Wheat Straw **T_2= paddy Straw** **T_3= Groundnut leaves and Straw**

T_4= Sugarcane Bagasses **T_5= Cotton Stalk** **T_6=Coconut Husk**

T_7= Pigeon Pea Straw **T_8= Banana Pseudo Stem**

was found in the wheat+ paddy straw mushroom (350 mg/100g) which was near to the values obtained by wheat and paddy straw during the first picking. Considering the overall data shown in Table 3, banana pseudostem resulted in highest magnesium content (186.77 mg/100g) while the pigeon pea straw led to the lowest magnesium content (115.13 mg/100g). The data indicates that in the first picking, amount of magnesium content was significantly higher in banana pseudostem (197.06 mg/100g) which was followed by groundnut leaves and stem (182.92 mg/100g). In second picking, amount of magnesium content was significantly higher in coconut husk (180.49 mg/100g) which was followed by banana pseudostem (176.49 mg/100g). An investigation conducted by Hoa *et al.* (2015) revealed that the magnesium content in mushrooms of the *Pleurotus* species ranged from 60.65 to 94.27 mg/100g which was slightly lower to the results obtained in our study.The data with respect to the copper content as shown in Table 4 revealed that in both the harvests pigeon pea straw resulted in significantly highest values (7.24 and 5.02 mg/100g respectively). The overall value indicates that the highest copper content was found in the pigeon pea straw (6.13mg/100g) whereas the lowest copper content was reported in the sugarcane bagasses (1.34 mg/100g). According to Hoa *et al*. (2015), oyster mushrooms cultivated in various substrates had copper contents that ranged from 0.11 to 0.35 mg/100g, which was lower than the outcomes of our study. Data from Table 4 showed that during the first picking, groundnut leaves and straw (8.60 mg/100g) had significantly higher iron content in comparison to paddy straw (6.19 mg/100g). During the second harvest, the maximum iron content was reported in groundnut leaves and straw (5.64 mg/100g) which was at par with paddy straw (5.50 mg/100g). The average data revealed that the groundnut leaves and straw gave the maximum iron content (7.12 mg/100g) while the cotton stalk resulted in least iron content (3.04 mg/100g). The results of the study are in line with those of Ahmed *et al*. (2009), who reported that oyster mushrooms had an iron content that ranged from 11.87 to 13.06 mg/100g, slightly higher than the results of our investigation. The overall average shown in Table 4 revealed that the groundnut leaves and straw gave the maximum Zn content (12.43 mg/100g) while the banana pseudostem resulted in minimum Zn content (5.88 mg/100g). The data indicates that the zinc content was significantly highest in groundnut leaves and straw (13.74 and 11.12 mg/100g respectively) which was followed by wheat straw (10.02 and 8.89 mg/100g respectively) in both the pickings. The zinc content in oyster mushroom grown on various substrates ranged from 7.61 to 11.45 mg/100g (Hoa *et al*., 2015), which is in agreement with our results.

Conclusion

Based on the present study, it can be inferred that oyster mushrooms cultivated on substrates like groundnut leaves and straw (T_3), paddy straw (T_2), and wheat straw (T_1) exhibited a notable increase in proximate content such as carbohydrates, crude protein, and crude fiber. Additionally, there was an elevation in antioxidant content; and an enhancement in mineral content. The results suggest that agricultural waste can be effectively redirected for mushroom cultivation, offering economic advantages to farmers, contributing to environmental protection by mitigating pollution from agricultural waste burning, and ensuring nutritional security for the broader population.

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Conflict of interest

The authors declare that they have no conflict of interest.

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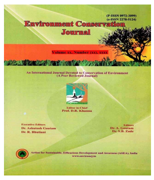

Single vs dual source surface energy balance model based actual evapotranspiration estimation

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ABSTRACT

The current study aims to inter-compare the performance efficiency of the single and the dual source surface energy balance modeling approaches, namely EEFlux and SETMI, respectively for real time catchment scale - crop water demand estimations. For this, the afore-stated two surface energy balance modelling approaches were applied on the Narmada Canal Project, Sanchore, Rajasthan, India for estimating catchment scale actual evapotranspiration (ETa) values for the Rabi cropping seasons of the years 2013-14 and 2018-19, after incorporating the basic satellite data derived inputs viz. Land use, Land surface temperature and Gridded weather data. Due to the non-availability of the catchment scale ground based daily reference evapotranspiration (ETo) values for the study area, the Global Land Data Assimilation System based gridded meteorological data product was utilized, as a substitute for obtaining observed actual evapotranspiration (ETa) values for the investigated Rabi seasons of the study area. These actual evapotranspiration values were compared with those estimated through the single source, EEFlux and the dual source, SETMI modelling approaches to ascertain their comparative performance efficiency through the use of the five statistical indices viz. Mean Absolute Error, Root Mean Square Error, Mean Bias Error, Nash-Sutcliffe Efficiency and the Index of Agreement. The investigations revealed almost at par performance of the two modelling approaches. However, it was concluded that in contrast to the more detailed dual source approach i.e., SETMI, the simple single source approach i.e., EEFlux seemed to be more promising due to its user-friendly implementation and input data automation.

Introduction

India currently ranks 13th among the 17 most water-stressed nations, presenting a concerning scenario. The impending impacts of global climate change, leading to a warmer climate, are expected to worsen

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this water scarcity. This is primarily due to an intensified hydrological cycle caused by rising temperatures, resulting in increased evaporation rates, shifts in precipitation patterns in terms of both intensity and seasonality, and changes in vegetation and land cover dynamics. In India, agriculture sector utilizes about 85% of available water resource followed by 8% and 7% by the domestic and industrial sectors respectively. Canal irrigation, coupled with groundwater, has undeniably played a vital role in accelerating agricultural production of India for meeting burgeoning population needs. Thus, in view of the looming climate change related threats it is likely that any further shortfall in water supply, especially in the already vulnerable arid and semi-arid regions, is likely to intensify the competition for water use across various economic, social, and environmental applications besides food production.

Canal irrigation techniques were originally designed with an intent to minimize disparities in water distribution among various users, however significant shortcomings have emerged in its functioning, primarily due to its reliance on a supply-based, rather than a demand-based system. This has adversely impacted its efficiency and effectiveness, giving rise to several various issues of concern such as uneven water distribution leading to over-irrigation in head reaches and reduced supplies in tail reaches along with inflexible water allocations. To implement an economically equitable water distribution irrigation system, a transition from supply based to near real time demand-based irrigation systems is essential. Accurate estimation of actual evapotranspiration (ETa) can play a pivotal role in this shift, as it represents the earth's principal outgoing energy flux related to the water cycle dynamics. Globally, the ETa accounts for nearly 60% of the mean precipitation inputs (Vorosmarty *et al.,* 2010) highlighting its significant implications for numerous geophysical applications including integrated water resources management, weather forecasting, climate change analysis, and irrigation water demand assessment. (Dai *et al.,* 2022; Kushwaha *et al.,* 2022; Salam *et al.,* 2020). Point scale field observations offer satisfactory solutions for ETa computation over homogenous surfaces. However, extrapolation of these point values over diverse spatial and temporal scales includes several underlying complexities due to the geographical variability in land surface and environmental conditions (Singh *et al.,* 2008; Teixeira *et al.,* 2009). These issues have been proficiently dealt with regular updates in remote sensing-based methodologies by indirectly quantifying spatially distributed parameters required for ETa estimation. Courault *et al.,* (2005) classified remote sensing-based evapotranspiration techniques in four major categories viz. Direct Empirical Methods, Residual Methods of Energy Budget, Deterministic Methods and Inference or Vegetation Index Methods. Amongst these, residual method of energy budget is the most widely used methods for ETa determination because of its ease of applicability and readily available remote sensing inputs.

Residual method of energy budget is further classified into single and dual-source model categories based on distinct treatment of the soil-plant-atmosphere interface. The dual-source approaches treat soil as well as vegetation components individually for apportioning linked turbulent heat fluxes while the single-source modeling approaches use individual resistance as a lumped composite parameter. Thus, for homogeneous vegetative conditions, a single-source modeling approach might be suitable. While, under heterogenous partially vegetated conditions, a two-source modelling approach that is capable of more genuine representation of the turbulent and radiation exchanges (Verhoef *et al.,* 1997; Merlin & Chehbouni, 2004; Norman *et al.,* 2000; Huntingford *et al.,* 2000) is expected to replicate the earth's surface energy balance with higher accuracy (Norman *et al.,* 1995). However, despite all this, it has been reported by several researchers that even an appropriately parameterized simple single-source modeling approach may represent surface energy balance satisfactorily (Kustas and Norman, 1996; Troufleau *et al.,* 1997; Bastiaanssen *et al.,* 1998). Though strengths and limitations of various residual methods of energy budget have been extensively reviewed (Gowda *et al.,* 2008; Li *et al.,* 2009; Wang and Dickinson, 2012; Liou and Kar, 2014; Kool *et al.,* 2014; Zang *et al.,* 2016) and mostly validated across irrigated croplands of USA, China, Mongolia, South Korea, and Japan yet scanning of literature revealed almost no assessment of such minimum resource and data demanding approaches on any resource/ data crunched water scarce regions of the world.

In view of the afore-stated knowledge gaps, the present study thus basically aims to cross-compare the performance efficiency of one of the latest and the most automated data intensive single source energy balance models viz., EEFlux with yet another latest dual source, but data-extensive, energy balance model named SETMI on the country's first sprinkler-fed Narmada Canal Command situated in the arid Rajasthan state of India, and to thereby assess the feasibility of such satellite based approaches for transforming the prevailing supply driven irrigation system to the near real time demand-driven system and for thereby mitigating climate induced water stresses in the resource-poor arid croplands.

Material and Methods

Study Area

The Narmada Canal Project (study) area (figure 1), located in the Barmer and Jalore district of Rajasthan, India, within the geographical co-ordinates of 24^0 37'- 25^0 18' N latitude and 71^0 3'- 71^0 52' E Longitude, comprises of 2.46 lakh ha command area. The climate of the region varies from arid to semi-arid as it falls in the two agroclimatic zones namely, the arid western plains and the transitional plains of Luni basin. Due to erratic, unevenly distributed and less than 500 mm annual rainfall along with substantial diurnal temperature variations, the study area experiences frequent crop failures due to droughts.

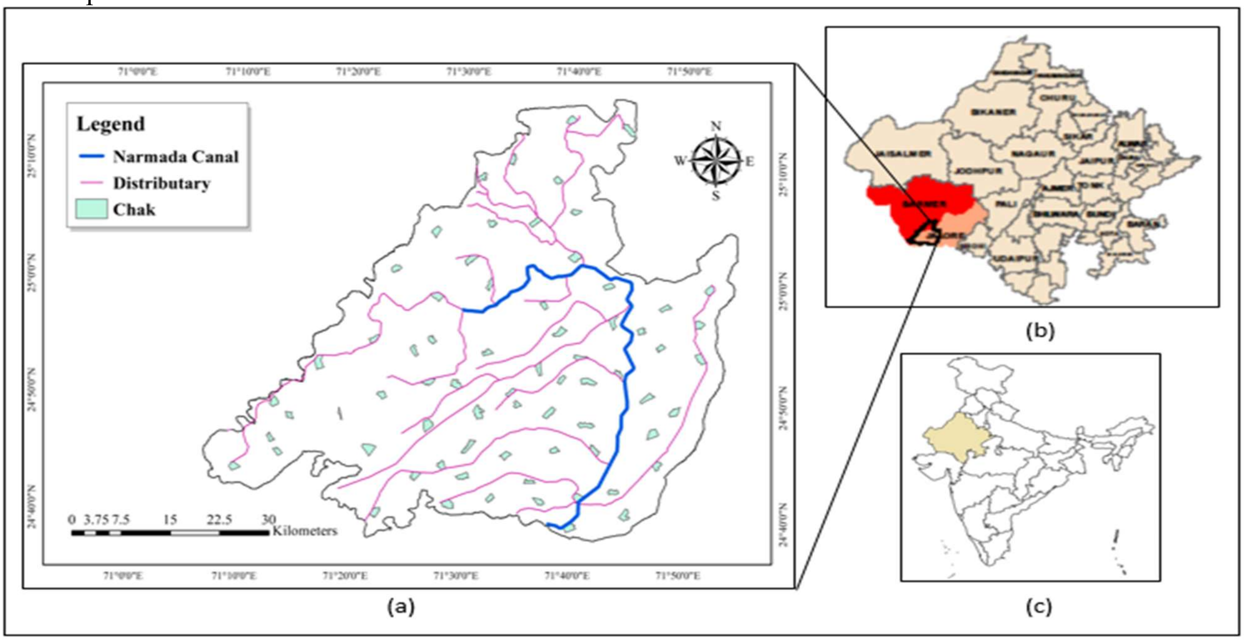

Figure 1(a): Location map of the study area (b) Study area boundary in Rajasthan state (c) Map showing Rajasthan state boundary within Indian national boundary

Modelling approaches for estimating actual evapotranspiration

EEFlux model

The Google Earth Engine Evapotranspiration Flux (EEFlux) is an automated version of METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration) which is developed and designed within the Google Earth Engine (GEE) (Allen *et al.,* 2007). This software is collaboratively developed by a group of researchers from the Desert Research Institute, University of Nebraska-Lincoln, and the University of Idaho, with financial assistance provided by the Google. EEFlux enable users to acquire evapotranspiration maps in a matter of seconds using Landsat 5,7 or 8 scenes stored in the GEE cloud platform (Allen *et al.,* 2015). EEFlux utilizes European Space Agency (ESA) GlobCover land use map with an approximate resolution of 300 m for Indian continent. For locations outside the United States, EEFlux utilizes Climate Forecast

System Reanalysis (CFSR) gridded weather data (http://cfs.ncep.noaa.gov/cfsr/) (Saha *et al.,* 2010) and six hourly CFSv2 operational analysis (Yuan *et al.,* 2011; Saha *et al.,* 2013). For current study Landsat 8 images were processed on EEFlux version 0.20.3.

SETMI model

The Spatial evapotranspiration modeling interface (SETMI) is a hybrid modelling interface (Neale *et al.,* 2012) combining Two Source Energy Balance (TSEB) ET modal (Norman *et al.,* 1995) and a reflectance-based crop coefficient (Kcbrf) water balance modal (Neale *et al.,* 1989). It was developed jointly by collaborators from Utah State University and the University of Nebraska-Lincoln, USA (Geli and Neale, 2012). This interface operates within the ESRI ArcGIS environment and is coded in Visual Basic.NET. In our study, only the TSEB model within the SETMI interface was used for ETa estimation. Required input included multispectral images, radiometric surface temperature images (in ^{0}C), land cover classification image and weather parameter table.

Model input data generation

The study area could be covered in three Landsat 8 satellite data tiles (having following paths/rows viz., 149/43, 150/43 and 150/42), that where directly downloaded from the https://earthexplorer.usgs.gov/ website and mosaiced together to achieve a single input image (Figure 2) for the entire study area, for the nearest satellite pass dates. Table 1 illustrates the exact dates for which the afore-stated satellite images were downloaded and mosaiced together for the study area. The so downloaded and mosaiced satellite images for the band Nos. 3, 4, and 5 of the Landsat 8 were subjected to level-1 supervised classification to generate land use/ land cover maps (as illustrated in Figure 3 and 4) under three primary land use classes viz. Cropped area, bare soil and open water while band 10 of Landsat 8 was used for generating the land surface temperature images through ArcGIS software.

Besides these afore-stated inputs, the SETMI model requires instantaneous and daily reference evapotranspiration (ETo) data to scale modelled instantaneous latent heat flux into daily ETa values after having ETo values multiplied with the crop coefficient values for the dominant crop being cultivated during Rabi season in the study area. However, due to the unavailability of ground based meteorological data for providing instantaneous meteorological parameters and daily ETo at the satellite overpass time for the study area, Global Land Data Assimilation System's gridded meteorological data product namely, GLDAS_NOAH025_3H was employed as a substitute. The Global Land Data Assimilation System (GLDAS) is a terrestrial modelling system developed jointly by the NASA Goddard Space Flight Center (GSFC) and National Oceanic and Atmospheric Administration and is available at a spatial and temporal resolution of $0.25^{0} \times 0.25^{0}$ and 3 hours from the reference site, https://ldas.gsfc.nasa.gov. Thus, the afore-stated three hourly GLDAS data files, in NetCDF format, were downloaded for the Rabi season of the 2013-14 and 2018-19 and executed in a MATLAB script to extract the relevant weather parameters in .xls format to compute ETo values using FAO Penman-Monteith equation (Allen *et. al*., 1998). Thereafter, the instantaneous value of ETo at satellite overpass time were determined by linearly interpolating ETo values available prior and after the satellite overpass time. Lastly, a weather parameter table was prepared as a Microsoft excel spreadsheet, containing instantaneous values of incident solar radiation, air temperature, wind speed, barometric pressure, vapour pressure and instantaneous and daily ETo. A detailed flowchart depicting the afore-stated methodology for estimating ETa through SETMI modelling framework is illustrated in figure 5.

As per the NCP's detailed project report, the study area has been reported to be predominantly cultivated with Cumin (*Cuminum cyminum*), having an average crop duration of 120-130 days, during Rabi season. Figure 6 illustrates growth stage specific crop coefficient (Kc) values for the Cumin crop. Thus, for computing the observed ETa values, the aforementioned crop coefficient values were multiplied by the ETo values computed through FAO Penman-Monteith equation using GLDAS datasets. The so obtained ETa values (i.e., the observed ETa) were compared with the SETMI and EEFlux model estimated ETa values (i.e., the predicted ETa) to assess their performance efficiency in terms of the following five statistical indices as illustrated in Table 2.

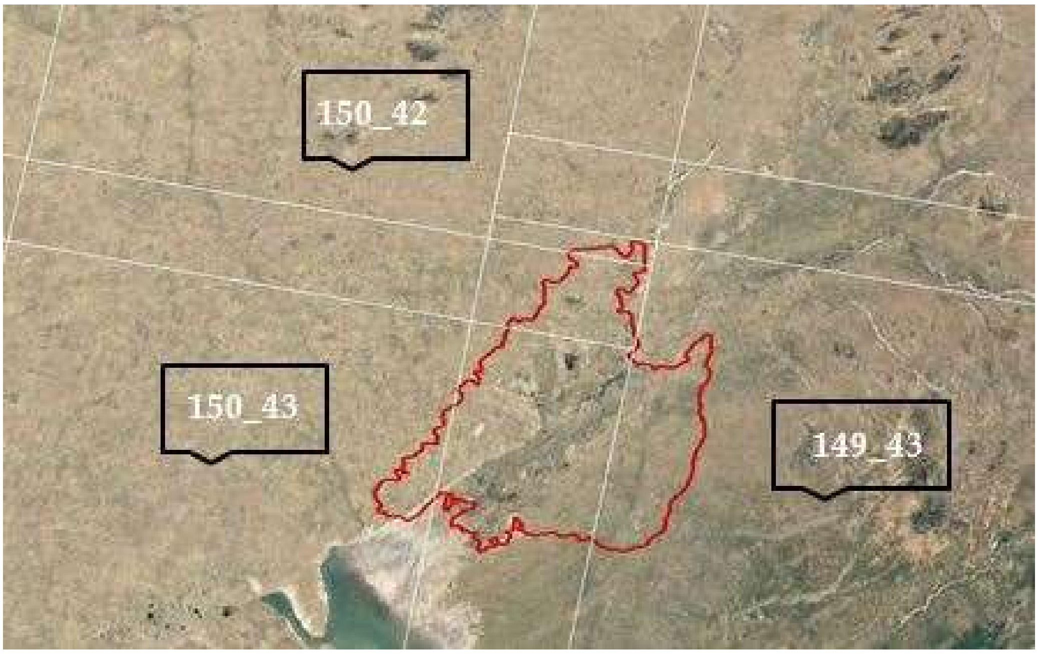

Figure 2: Mosaiced Landsat 8 satellite images for the study area

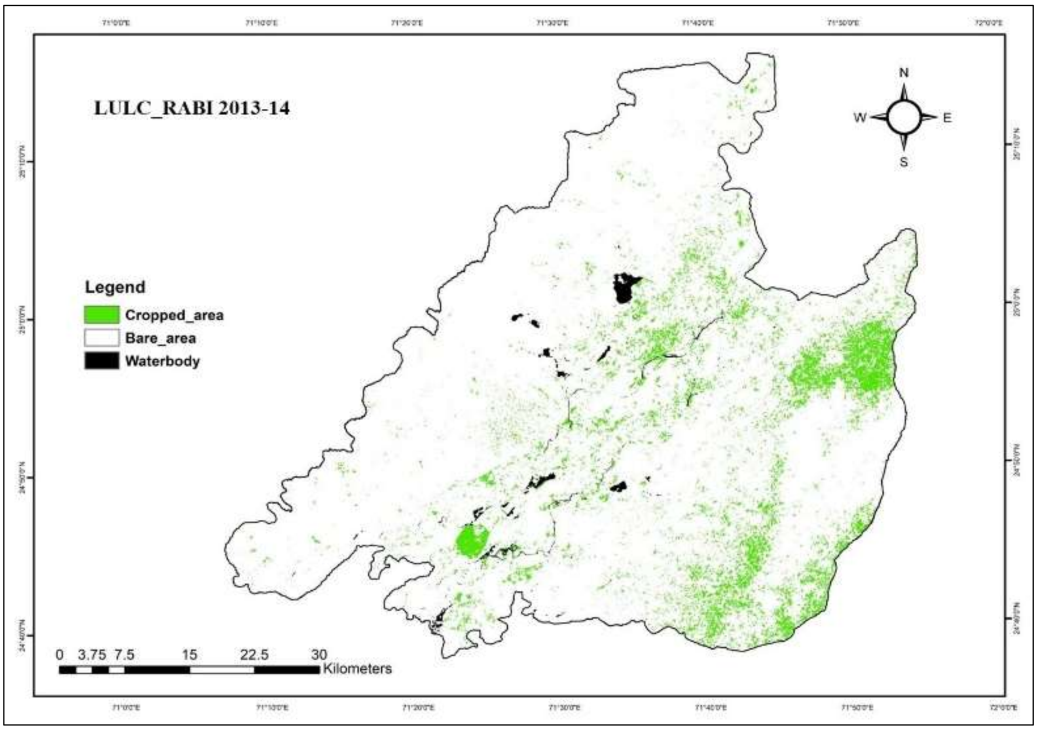

Figure 3: Representative land use/ land cover map of study area during Rabi season (2013-14)

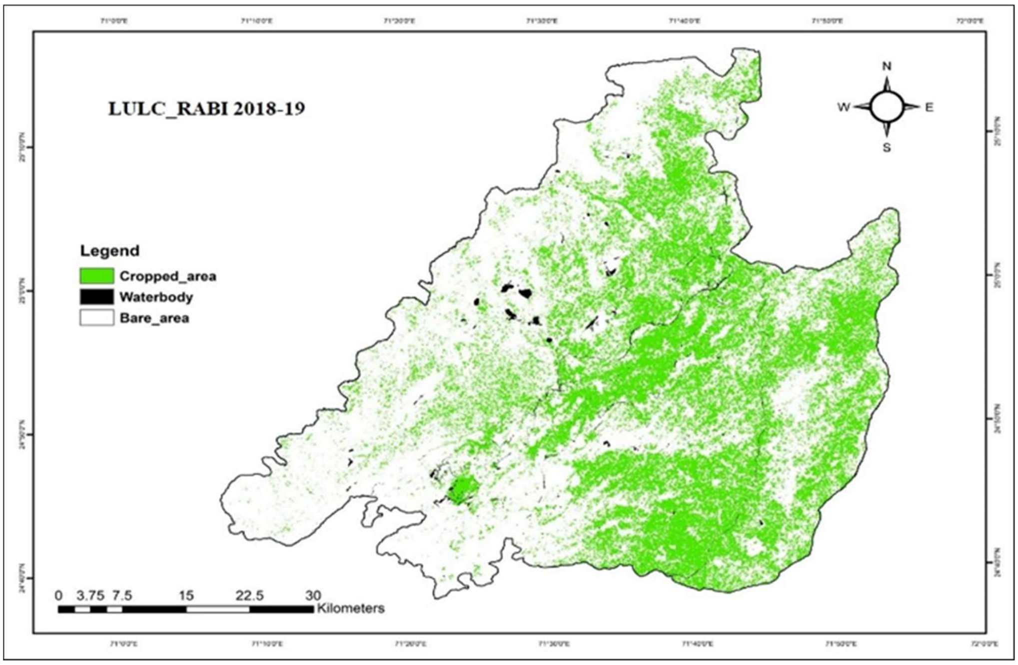

Figure 4: Representative land use/ land cover map of study area during Rabi season (2018-19) model performance assessment

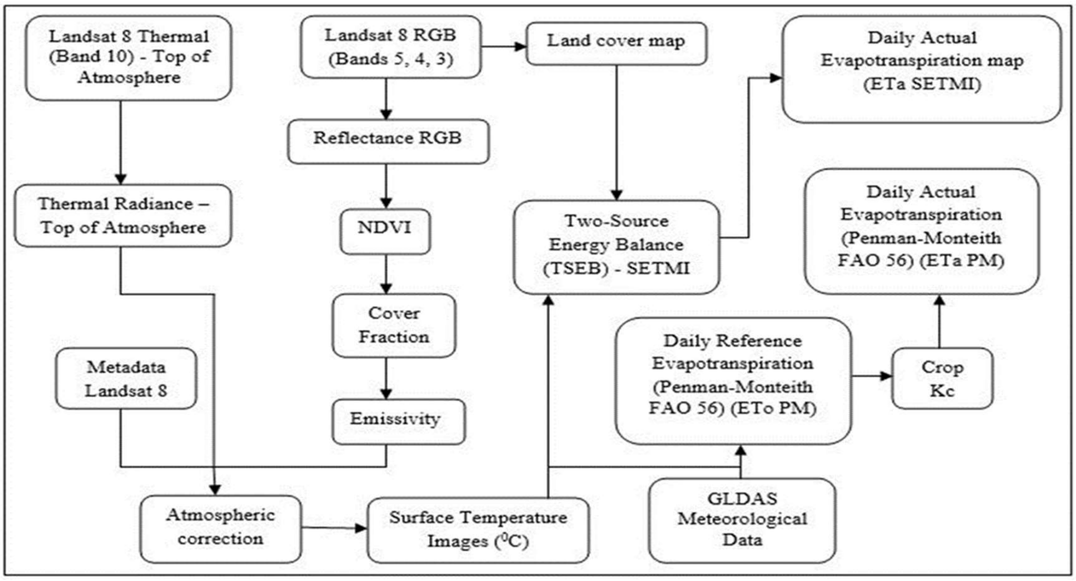

Figure 5: Flow chart depicting methodology used in actual evapotranspiration (ETa) estimation using SETMI model

The Mean Bias Error (MBE) was employed to assess the tendency of the model to under or over-predict. Though, a value of zero denotes no bias but it need ot necessarily represent an error absence. Thus, besides MBE, Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) were also deployed to not only determine the average errors, irrespective of their directions, in the model prediction sets but to also quantify their spread. Nash-Sutcliffe efficiency (NSE), a normalized

Table 1: Path/ Row specific dates of the downloaded Landsat 8 images during crop growing season for the study area

Crop growth stage specific downloaded Images	Rabi season 2013-2014 (15th Nov – 15th Mar)			Rabi season 2018-2019 (15th Nov – 15th Mar)		
	149/43	150/43	150/42	149/43	150/43	150/42
Initial	26-11-2013	17-11-2013	17-11-2013	24-11-2018	01-12-2018	01-12-2018
Vegetative	12-12-2013	03-12-2013	03-12-2013	26-12-2018	02-01-2019	02-01-2019
Mid-season	28-12-2013	19-12-2013	19-12-2013	11-01-2019	18-01-2019	18-01-2019
Late-season	02-03-2014	09-03-2014	09-03-2014	27-01-2019	03-02-2019	03-02-2019
Late-season	-	-	-	28-02-2019	07-03-2019	07-03-2019

*** Images for the dates illustrated in each row under columns marked Rabi season (2013-14 and 2018-19) were mosaiced together to generate a single image of the study area**

Table 2: Description for various statistical indices used for model performance assessment

Statistic	Mathematical Expression	Range	Best
Mean Bias Error	$\mathrm{MBE} = (1/N)\sum_{i=1}^{N}(Pi - Oi)$	$-[\left(\frac{1}{N}\right)\sum_{i=1}^{N}(Oi)]$ to ∞	0
Root Mean Square Error	$\mathrm{RMSE} = \sqrt{(1/N)\ \sum_{i=1}^{N}\ (Pi - Oi)^2}$	0 to ∞	0
Mean Absolute Error	$\mathrm{MAE} = (1/N)\sum_{i=1}^{N}\lvert Pi - Oi\rvert$	0 to ∞	0
Nash Sutcliffe Efficiency	$\mathrm{NSE} = 1 - [\frac{\sum_{i=1}^{N}(Pi - Oi)^2}{\sum_{i=1}^{N}(Oi - \bar{O})^2}]$	$-\infty$ to 1	1
Index of Agreement (d-index)	$d = 1 - [\frac{\sum_{i=1}^{N}(Oi - Pi)^2}{\sum_{i=1}^{N}(\lvert Pi - \bar{O}\rvert + \lvert Oi - \bar{O}\rvert)^2}]$	0 to 1	1

Pi = Predicted ETa; Oi = Observed ETa; $\overline{P}, \overline{O}$ = Mean of predicted and observed ETa respectively; N = Total number of data record

Table 3: Catchment scale mean observed vs. predicted ETa of the agricultural areas in Narmada Canal Project during (2013-14) Rabi season

Date	Crop Growth Stage	$GLDAS\_ET_0$	Kc	GLDAS_ETa	EEFlux_ETa (mm/d)		SETMI_ETa (mm/d)	
					mean	σ	mean	σ
26/11/2013	Initial	3.56	0.48	1.71	1.59	0.61	2.88	0.69
12/12/2013	Vegetative	3.47	1	3.47	2.4	0.79	2.38	0.43
28/12/2013	Mid-season	3.38	1.12	3.79	4.38	1.49	2.97	0.94
02/03/2014	Late-season	4.58	0.4	1.83	2.21	0.71	3.32	1.07

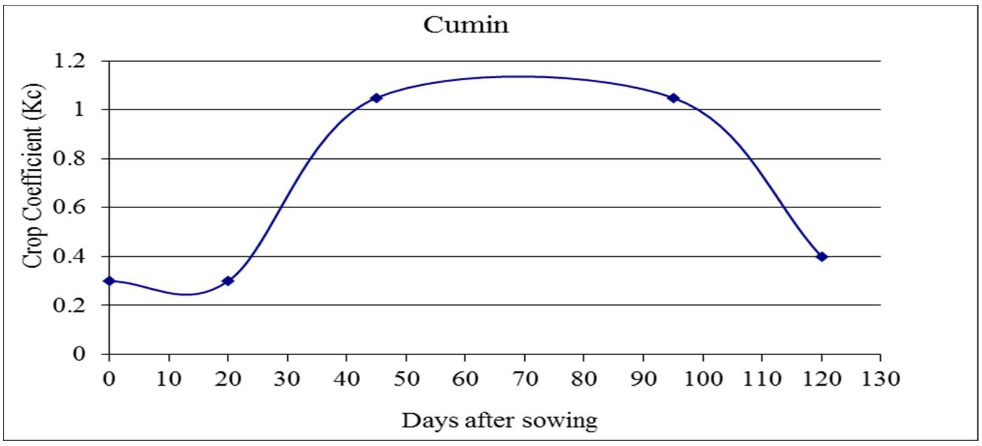

Figure 6: Seasonal crop coefficient values for Cumin (*Cuminum cyminum*) crop

statistical index was also utilized to evaluate the predictive capability of the model. Positive values of NSE indicate an acceptable performance level while negative values designate unsatisfactory performance (Nash and Sutcliffe, 1970; Moriasi *et al.,* 2007). However, as NSE is particularly sensitive to high peaks therefore another index of agreement (d-index) that quantifies the prediction error between 0 and 1 was also applied. The mathematical expressions for all these statistical indices are provided in Table 2.

Results and Discussion

Seasonal trend of EEFlux estimated actual evapotranspiration

The ETa values estimated through EEFlux modelling approach (EEFlux-ETa) during the Rabi season of 2013-14 (Table 3) exhibited considerable variation, ranging from the lowest value of 1.59 mm/d (with a standard deviation, σ of 0.61 mm/d) during initial crop growth stage (i.e., on 11-26-2013) to the highest value of 4.38 mm/d (with σ of 1.49 mm/d) during mid-crop growth stage (i.e., on 12-28-2013). The lower ETa observed during the initial crop growth stage could be attributed to smaller leaf areas and limited transpiration rates while, as the crop matured and advanced through its developmental stages, the ETa values gradually increased, reaching their peak during the mid-crop growth stage. This escalation could be lucidly attributed to the increased transpiration due to increased crop growth and ground coverage, which eventually reached its maximum during the mid-crop growth stage. Subsequently, with the onset of the late-crop growth stage, there was a gradual decline in ETa primarily due to the crop maturity and the prevailing dry soil conditions. The seasonal ETa trend of estimated through the EEFlux model during the Rabi season 2013-14 was thus observed to completely conform to the widely accepted pattern of ETa dynamics during any crop growing season. Similarly, during the Rabi season of 2018-19 (Table 4), the EEFlux model computed ETa values were observed to be ranging from the lowest value of 0.92 mm/d (with σ of 0.74 mm/d) during initial crop growth stage to the highest value of 2.43 mm/d (with σ of 1.47 mm/d) during late-crop growth stage. However, during 2018-19 Rabi season the ETa values during mid-crop growth stage were observed to be significantly lower than those observed during the late-crop growth stage of the year 2018-19 primarily due to the desert locust (*Schistocerca gregaria*) attack during Rabi season of the 2018-19, as reported by the local farmers and authorities of the study area which resulted in significant decline in the overall crop cover and thus ETa of the study area.

Seasonal trend of SETMI estimated actual evapotranspiration

In contrast to the EEFlux model the SETMI estimated ETa (SETMI_ETa) values exhibited significant deviations from the general trend of widely accepted pattern of ETa dynamics during any crop growing season as these were observed to be the highest during late crop growth stage (3.32 mm/d with σ of 1.07 mm/d) and the lowest (2.38 mm/d with σ of 0.43 mm/d) during crop vegetative stage. Even for the subsequent Rabi season of 2018-19, the SETMI model predicted the highest ETa value (2.21 mm/d with σ 0.67 mm/d) for the initial crop growth stage and the lowest value for the late crop growth stage (ETa of 1.4 mm/d and σ 0.63 mm/d). Further, even the mid-season SETMI predicted ETa value was observed to be lower than that for the late crop growth stage (1.86 mm/d with 0.74 mm/d). Though this decrease can presumably be attributed to the incident desert locust attack during that season/ year yet it appeared to be also associated to perhaps the poor parameterization of the TSEB algorithm within the SETMI interface, specifically during the initial and the late crop growth stages as evident from the SETMI estimated ETa trend for the Rabi season of 2013-14.

Observed vs predicted actual evapotranspiration

Figures 7 and 8 illustrate observed (i.e., GLDAS_ETa, in mm/d) vs. predicted actual evapotranspiration rates (Modelled_ETa, in mm/d) as obtained through the EEFlux (EEFlux_ETa, Table 3 and 4) and the SETMI models (SETMI_ETa, Table 3 and 4) for the Rabi seasons of (2013-14) and (2018-19), respectively. While for assessing the comparative performance efficiency of the two modelling approaches, the afore-generated data were subjected to the statistical indices illustrated in Table 5. Cross comparison of these statistical index values revealed that the EEFlux model seemed to be associated with much lower RMSE values (0.64 mm/d) than the SETMI model (1.17 mm/d), during 2013-14 while SETMI model seemed to be associated with much lower RMSE values (1.83 mm/d) than the EEFlux model (2.04 mm/d), during 2018-19. However, on considering all data points for both the study periods/ seasons, the RMSE values for both the modelling approaches were found to be at par (i.e., 1.57 to 1.58 mm/d). Though this was also observed to be the case for the Mean Absolute Error (MAE) index values, yet the analysis revealed that the overall MAE values for both seasons (Rabi 2013-14 and Rabi 2018-19) put together were significantly

Table 4: Catchment scale mean observed vs. predicted ETa of the agricultural areas in Narmada Canal Project during (2018-19) Rabi season

Date	Crop Growth Stage	GLDAS_ET0	Kc	GLDAS_ETa	EEFlux_ETa (mm/d)		SETMI_Ea (mm/d)	
					mean	σ	mean	σ
24/11/2018	Initial	4.02	0.4	1.61	0.92	0.74	2.21	0.67
26/12/2018	Vegetative	3.56	1.12	3.99	1.4	0.92	1.81	0.66
11/01/2019	Mid-season	3.77	1.14	4.30	1.05	0.36	1.86	0.74
27/01/2019	Late-season	3.81	1.1	4.19	2.43	1.47	1.88	0.83
28/02/2019	Late-season	4.80	0.4	1.92	1.72	0.85	1.4	0.63

Table 5: Values of agreement indices for computing model performance

Statistical Indices	Rabi Period_2013-14		Rabi Period_2018-19		Both Seasons Pooled	
	EEFlux	SETMI	EEFlux	SETMI	EEFlux	SETMI
RMSE (mm/d)	0.64	1.17	2.04	1.83	1.58	1.57
MAE (mm/d)	0.54	1.14	1.70	1.61	1.18	1.40
MBE (mm/d)	0.05	-0.19	1.70	1.37	0.97	0.68
NSE	0.80	0.34	-0.06	0.15	0.19	0.21
d-index	0.95	0.78	0.29	0.31	0.63	0.55

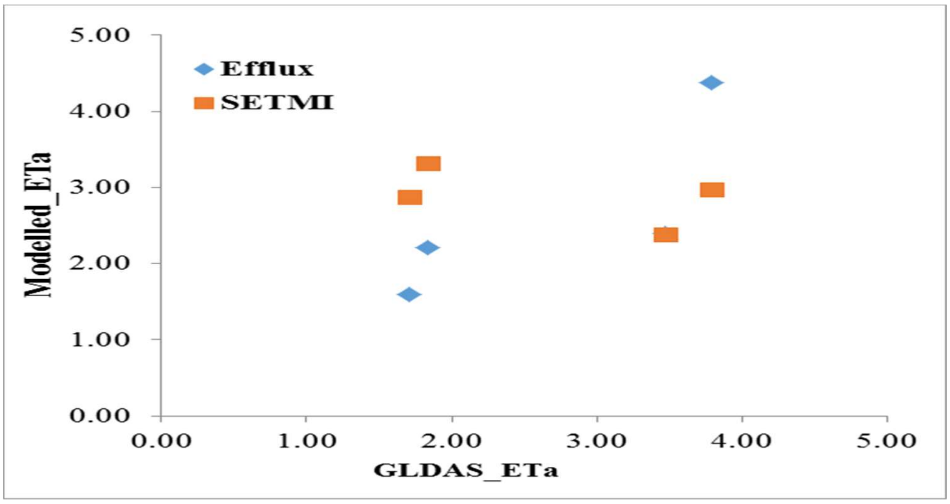

Figure 7: Observed verses predicted actual evapotranspiration (ETa) for Rabi season of 2013-14

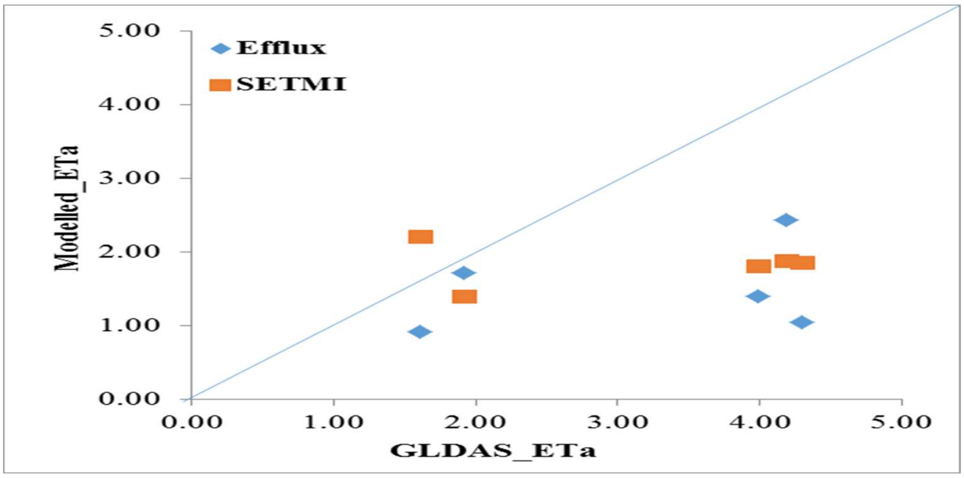

Figure 8: Observed verses predicted actual evapotranspiration (ETa) for Rabi season of 2018-19

lower for the EEFlux model (1.18 mm/d) than the SETMI model (1.40 mm/d). Further, though the EEFlux model was observed to be associated with somewhat higher bias than the SETMI model (as evident from the statistics on the pooled data in last two column of the row illustrating MBE index values under Table 5) yet the pooled Nash-Sutcliffe Efficiency index (NSE) and the index of agreement (d-index) values for the two approaches appeared to be quite comparable, with EEFlux modelling approach having a visible edge over the SETMI modelling approach particularly during 2013-14 Rabi season.

The investigations thus illustrated at par performance of both EEFlux and SETMI models in the arid region of the Narmada Canal Project of Rajasthan, India and thereby re-iterated that it's not necessary that a more detailed two-source surface energy balance approach, capable of computing surface energy balance of heterogeneous surfaces with greater accuracy, be outperforming a simple single-source model under all situations (Kustas and Norman, 1996; Troufleau *et al.,* 1997; Bastiaanssen *et al.,* 1998). In fact, our experience revealed that the dual source, SETMI modelling approach required more careful model input data parameterization, especially with respect to the target area's land use and crop coefficient values, as compared to the EEFlux model where the same were completely automated thereby decreasing the negative impacts of the inferior user skill set or user-errors on the quality of the generated model inputs and thus model-reproducibility in terms of its outputs or performance. These results were observed to be in close conformity with even those obtained by French, *et al.* (2015), Timmermanns, *et al.* (2007) and Liaqat and Choi (2015). Thus, the present study strongly recommended the use of single-source surface energy balance approach namely EEFlux particularly for the arid regions of the developing nations, where limited data availability and computational resource pose significant challenges.

Conclusion

Remote sensing-based single and dual-source surface energy balance modeling approaches represent cutting-edge techniques for operationalizing actual evapotranspiration-based demand driven irrigation systems. Normally the more detailed dual-source surface energy balance approaches are assumed to be superior to the simpler single-source energy balance modelling approaches. However, the present investigation, that was primarily aimed at assessing the comparative performance efficiency of the single-source, EEFlux and the dual-source, SETMI models for estimating actual evapotranspiration flux over the Narmada Canal Command area of the arid Rajasthan state of India, clearly showed that the afore-stated assumption need not be universally applicable as in the present investigation the test single source model namely, EEFlux seemed to be performing at par with the dual source, SETMI model. In fact, the present study demonstrated distinct advantages of the single source EEFlux model over the dual source SETMI model due to its user friendly, automated implementation and low input data requirements thereby making it the most suitable approach for particularly the resource crunched and vulnerable arid regions of the world having limited input data and computational resources.

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Conflict of interest

The authors declare that they have no conflict of interest.

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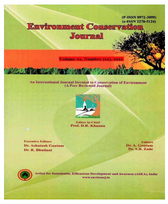

Evaluation of the toxicological effects of uranium on human health in Chandrapur, Maharashtra, with reference to the water quality index

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ABSTRACT

Groundwater is an important resource and approximate 80% of the world's population depends solely on it to satisfy their needs. In the present investigation groundwater quality was assessed using WQI. For the same parameters viz, temperature, pH, conductivity, DO, alkalinity, TDS, sulphate, fluoride, bicarbonate, chloride, uranium, total hardness, calcium and magnesium hardness were assessed during post monsoon period in November 2021 in the Chandrapur region. For conducting this research total 116 groundwater samples were collected from different hydrological stations for the assessment of WQI. WQI is an important tool to assess quality of water for drinking and is classified as excellent to unsafe, i.e., 0-100 score. In this investigation WQI was found to be in the range between 27.63-674.56 exceeding both minimum and maximum score. The results of the present investigation showed that only 5.17% of water is safe for drinking,18% of water indicated poor water quality, 15% of water has very poor water quality and 77% of water is unsuitable for drinking purpose and proper treatment is required before use. During this investigation uranium in groundwater was also assessed considering its chemotoxical and radiological effects on human health. The chemotoxical and radiological effects were analyzed adopting standard equations given by USEPA. The radiological risk of mortality and morbidity was found to be 1.37E-05-1.47E-05, respectively. Thus, presence of uranium was noted and radiological risk was found to be below the permissible limit of AERB standard. The chemical toxicity of average value of Lifetime Average Daily Dose (LADD) and Hazard Quotient (HQ) was observed 0.315 and 0.00571, respectively and chemical toxicity of LADD was found to be in 8.62% sample population and above the permissible limits which can affect human health and can have kidney toxicity, bone and lung toxicity.

Introduction

Groundwater can be found practically anywhere beneath the Earth's surface. The earth's surface is not uniformly distributed. However, there are many localized aquifer sources and segments with similar personalities (Vasanthavigar *et al.*, 2010; Ahamad *et al.,* 2022). The quality of groundwater changes with the level of water, seasonal fluctuations, dissolved ions and subterranean surroundings (Gebrehiwot *et al.*, 2011; Ruhela *et al.,* 2022a; Ahamad *et al.,* 2023). According to the World Health Organization (WHO), in 2017, more than 80% of all human infections were waterborne. Because groundwater is polluted, ensuring its safety is challenging (Ram *et al.*, 2021; Bhutiani *et al.*, 2021). An appropriate analysis of the features of groundwater reservoirs is necessary to establish a sustainable exploitation of groundwater resources for further growth and requirements because there are many elements that might affect groundwater quality (Carrera-Hernandez and Gaskin, 2006; Chenini and Ben, 2010). To help with enhancing groundwater management techniques (protection and

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sustainability from degradation), hydrogeochemical information must be gathered for the area (Vasanthavigar M., *et al.*, 2010; Ruhela *et al.,* 2022b). An extensive hydrological study based on policy deployments is required in each area where drinking water will be extracted. In these cases, water quality assessment indices (WQIs) are commonly used as collection and management technologies for monitoring water quality. In general, indices were created to summarize water quality data in a conveniently expressed and unstainable format. By definition, indices contain less data than the raw data that they summarize. As a result, indices are typically useful for illustrative purposes and common questions. Depending on the available data, various approaches to developing an index of water quality are possible (Saeedi *et al.*, 2010; Bhutiani *et al*., 2018). The quality of recharged water, atmospheric rainfall, coastal surface water and lithospheric geochemical processes all influence groundwater quality. Periodic changes in groundwater quality can be caused by changes in the origin and composition of recharged water as well as hydrologic and human factors (Vasanthavigar M., *et al*., 2010). In the present study, the water quality index was assessed in combination with uranium in groundwater considering its chemical and radiological risk. The presence of groundwater uranium is affected by a variety of factors, including geomorphological, lithological and other geological conditions. The uranium concentration in groundwater is affected by natural and anthropogenic activities (Duggal *et al*., 2017; Kumar *et al*., 2016). Despite the fact that uranium is naturally present in the environment, has no known positive metabolic activities and is considered a nonessential constituent, when uranium is acquired in humans, it can cause radioactive and chemical effects in the form of numerous different health hazards (Duggal *et al*., 2020; Sharma *et al*., 2016; Bojago *et al*., 2023).

Materials and Methods

Study Area

Chandrapur is part of the Vidarbha region of Maharashtra and covers an area of 11,364 km^2. It is also called the black gold city due to the dominance of coal mines around the city (Environmental Status Report, 2007). The latitude and longitude of the district are 19.30’N to 20.45’N and 78.46’E, respectively. The district is located within the Wainganga and Wardha Basins and flows through the boundaries of the Eastern and Western regions of the district (CGWB,2011). The sources of water-bearing formations in this district are Deccan Trap Bsalt, Vindhya Limestone, Alluvium, Lower Gondwana sandstone and Archean metamorphic rocks (CGWB, 2009; Satapathy *et al*., 2009).

Sample collection and preservation

In the present study, sample collection and preservation were performed according to standard methods given in APHA and AWWA (2017). With the help of the grid map, 116 groundwater samples were collected from 15 different locations in the district during the postmonsoon season. The sampling bottles were soaked in 10% HNO3 overnight and were washed before sample collection. The clean bottles were used for the collections, and water samples were collected without aeration. The samples were sealed tightly with the help of cello tape and labeled after collection. In situ parameters such as temperature, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), pH, oxidation–reduction potential (ORP), salinity, etc., were measured with the help of a Bluetooth multiparameter portable kit, and off-situ chemical parameters such as alkalinity (titration), total hardness (EDTA titration method), chloride, bicarbonate, fluoride, sulphate, and uranium were analyzed with the help of standard methods prescribed by the APHA and AWWA and NEERI in the laboratory; in particular, uranium was analyzed at the KITS College, Ramtek, by using an LED fluorimeter.

Water quality index

The water quality index is a mathematical tool for calculating a single value that represents water quality based on multiple water quality metrics. The WQI is used to measure water quality parameters because it allows the creation of a numerical expression that can be used to characterize water quality. The water quality index categorizes the water quality data into a single value using a methodological approach or model. The WQI calculations consider all water quality criteria and are based on the suitability of both surface water and groundwater for their desired use (Ghoderao, *et al.,* 2022).

$$Qi = \frac{(Vobserved - Videal)}{(Vstandaed - Videal)} \times 100 \quad \text{------------- 1}$$

where
Qi = Quality rating of the i^{th} parameter for a total of n^{th} water quality parameters.
$V_{observed}$ = Actual value of the water quality parameter obtained from laboratory analysis
V_{ideal} = the ideal value of that quality parameter can be obtained from the standard tables.
V_{ideal} for pH = 7 and for other parameters is equal to zero and DO
V_{ideal}= 14.6 mg/L
$V_{standard}$ = Recommended

WHO standard of the water quality parameter.

Calculation of Unit weight (Wi):
The unit weight was calculated by a value inversely proportional to the recommended standard (Si) for the corresponding parameter using the following expression:

$$Wi = \frac{K}{Si} \quad \text{-------------------------- 2}$$

where
Wi = Unit weight for the nth parameter,
Si = Standard permissible value for the nth parameter
K = proportionality constant. For the sake of simplicity, K is assumed to be 1,

The overall WQI was calculated by aggregating the quality rating with unit weight linearly using the following equation:

$$WQI = \frac{\sum WiQi}{\sum Wi} \quad \text{----------------------------- 3}$$

where Qi = quality rating,
WI = Unit weight

Radiological risk assessment
The radiological risk is nothing but the excess cancer risk (ECR) (Patra, *et al*., 2013). The excess cancer risk was determined with the following formula provided by the United States Environmental Protection Agency (USEPA):

$$ECR = U \times Risk\ factor \quad \text{------------------------- 4}$$

where the uranium concentration (µg/L) is converted into Bq/L.
The conversion factor is 0.025 Bq/L.

R is the risk factor and is calculated by the following equation:

$$Risk\ Factor\ (L/Bq) = Risk\ Coefficient \times IR \times TEP \quad \text{------------------ 5}$$

where r is the uranium risk coefficient for mortality and mobility and was taken as 1.19×10^{-9} and 1.84×10^{-9} Bq/L, respectively (Mehra, *et al.,* 2017).
The water ingestion rate (IR)= 1.38 (L/day) (Kale and Kulkarni, 2018).
The total exposure duration days (TEP) = 70 years, i.e., 25550 days for adults (Rani *et al.* 2013; WHO, 2011; Duggal and Rani, 2017)
TEP =3650 (Sharma *et al*., 2016) days for children. This equation was used for the assessment of mortality and morbidity related to cancer risk resulting from groundwater consumption of uranium over a lifetime.

Chemical toxicity risk assessment
The consumption of uranium-contaminated groundwater can cause kidney and bone damage because of chemical toxicity (Kale, 2021). The following equation is used to assess the lifetime average daily dose (LDAA) (WHO, 2011; Bhardwaj, *et al*., 2015):

$$LADD\ (\mu g/L/Kg/Day) = \frac{U \times IR \times EF \times LE}{BW \times AT} \quad \text{----- 6}$$

where
U = the uranium concentration in the water sample (µg/L)
IR (Ingestion Rate) =1.38 (L/Day)
EF (exposure frequency) = 365 (day/year) (Ali *et al*., 2019)
BW (body weight)=70 kg
AT (average time of exposure) = 25550 days for adults (Kale, *et al*., 2018).

Hazard quotient (HQ)
The degree of effect of uranium through water ingestion is estimated such that an HQ value less

than 1 (<1) indicates no adverse health issues (Bajwa, *et al*., 2015). The following formula was used to calculate HQ:

$$HQ\ (\mu g/L/Kg/Day) = \frac{LADD}{RfD} \text{ -------- } 7$$

where Rfd is the reference dose. Rfd=4.53 µg/kg/day (WHO, 2011 and Duggal, *et al*., 2016; Ganesh, *et al*., 2020).

Assessment of the annual effective dose (AED)

The calculated annual effective dose from uranium consumption from groundwater is shown in Table 2.

$$\mathrm{AED} = \mathrm{AC} \times \mathrm{F} \times \mathrm{I} \times 365 \text{-------------------------- } 8$$

where AC (average concentration of uranium) = (Bq/L)
F (effective per unit intake) (µSv/year/Bq/L) = 4.5×10^{-8}
I (age-dependent daily water intake) (L/Day) = 503.7 L (1.38×365).

Cumulative Dose

The cumulative dose is the total dose resulting from exposure to ionizing radiation throughout a human being. The cumulative dose was calculated by using the following formula:

$$\text{Cumulative dose} = \mathrm{DE} \times \text{lifetime} \text{ -------------- } 9$$

DE means the annual effective dose, and lifetime = 70 years (WHO, 2011; ICRP, 2012).

qualitative analysis of water used to neutralize an acid. During the present investigation, the alkalinity of the groundwater ranged from 84-660 mg/L (Table 3). Similar findings were reported by Khanna and Bhutiani (2011) and Ruhela *et al.* (2017). In the present study, chloride concentrations were reported to be in the range of 05.99-903.71 mg/L (Table 3). Near-minimum and maximum values were observed by Tyagi and Malik. 2018; Arya and Gupta, 2013. Hardness is the soap-consuming capacity of water (WHO, 2009). The total hardness of the study region ranged from 144-1000 mg/L (Table 3), which supports the results of Kamboj *et al.* (2018). Calcium occurs in the presence of gypsi-ferrous material, limestone, and gypsum dolomite. The calcium hardness of the groundwater during the study period ranged from 60-644 mg/L (Table 3). These

Results and Discussion

The following parameters were assessed for calculating the WQI

The alkaline material used in residential and industrial purposes contributed to the increasing pH. In the present study, the pH was observed to range from 4.7-8.11 during the postmonsoon season (Table 3). Yadav and Mishra (2014) observed the same minimum or maximum results for groundwater pH, which supports our investigation. The salinity risk and quality of groundwater can be determined with the help of electrical conductivity (Mahalakshmi and Rivachandrabose, 2021; Rao, *et al*., 2019). During the present study period, ECs were observed in the range of 370-5260 µS/cm (Table 3). Similar results were observed by Mahalakshmi and Rivachandra bose, 2021, Rao *et al.,* 2019, supporting our results. In the present investigation, the TDS concentration was found to be in the range of 106-1981 mg/L (Table 3). The TDSs, which include organic salts such as sulfate, bicarbonate, chlorides, sodium, potassium, calcium and magnesium, as well as organic salts, are dissolved in water. Similar results were observed by Ruhela *et al*., 2017. DO determines the anaerobic and aerobic organisms involved in changes in biological processes. DO plays an important role in aerobic treatment processes for the purification of industrial and domestic wastewater. In the present study, DO concentrations ranged from 1.23-2.86 mg/L (Table 3). Similar results were observed by Bhutiani *et al*., 2018; Kumar *et al.,* 2012). The alkalinity is the
approximate results were also reported by Arya and Gupta (2013). In the present investigation, the magnesium salt concentration in the groundwater was found to be in the range of 8-676 mg/L (Table 3). These approximate results were also reported by Arya and Gupta (2013). Sulfate is a natural observing mineral and is used in various chemical industries. It is discharged in water by industrial wastes that increase the sulfate concentration (Ingham, 2013). In the present study, groundwater sulfate concentrations were found to be within this
range. Natural spreading salts such as KCl, NaCl and $CaCl_2$ are chloride-containing compounds. The weathering process absorbs chloride from rocks into water and soil (WHO, of 1-198 mg/L (table 3), and similar results were observed by Dandge and Patil, 2022. The concentration of bicarbonate increases in

groundwater due to weathering (Srinivasamoorthy *et al.*, 2008). The concentration of uranium in groundwater is governed by the availability of HCO_3 ions in solution (Thivya, *et al.*, 2021). In this research, the bicarbonate concentration was found to be in the range of 0.8-67.6 mg/L (Table 3). Similar results were observed by Chandrashekhar *et al.*, 2021**.** The consumption of groundwater with a high concentration of fluoride causes dental fluorosis. In this research, the concentration of fluoride in groundwater was found to be in the range of 0.3-15.5 mg/L (Table 3). Supporting results were reported by Kumar *et al.*, (2018) and Panda *et al.*, (2019). The long-term consumption of elevated concentrations of uranium causes chronic health effects such as neurotoxicity, reproductive toxicity, pulmonary toxicity and hepatotoxicity (Ma, *et al.*, 2020). In the present research, the concentration of uranium was found to be in the range of 0.01-135.98 ppb (Table 3). Supportive results were observed by Rani *et al.*, 2013 in northern Rajasthan.

Table 1: Water quality index, status and possible usage of the water (Chatterji and Raziuddin ,2002)

Water Quality Index Level	Water Quality Status	Possible Usages
0-25	Excellent water quality	Drinking, irrigation and industrial
26-50	Good water quality	Drinking, irrigation and industrial
51-75	Poor water quality	Drinking and industrial
76-100	Very poor water quality	Irrigation
>100	Unsuitable for drinking	Proper treatment required before use

Water quality index

The water quality index represents information about water bodies in the most understandable form to the general public and classifies water into excellent to unsafe forms (Dandge and Patil, 2022). During thisThe investigation WQI of the study area was calculated and is shown in Table 4. A WQI ranging from 0-25 indicates excellent water quality, from 26-50 indicates good water quality, from 51-75 indicates poor water quality, from 76-100 indicates very poor water quality and above 100 indicates unsuitable water quality. As a result, 77% of the samples were unsuitable for drinking purposes. The values indicate that the groundwater quality in the Chandrapur district in the study area belongs to the good to unsuitable class. Similar results were observed by Ram *et al.* (2021) for groundwater quality assessment using the water quality index (WQI) and Batabyal and Chakraborty (2015) for hydrogeochemical and water quality indices in the assessment of groundwater quality for drinking purposes.

Assessment of excess cancer risk

During this investigation, the ECR for morbidity and mortality was calculated for a 70-year-old adult. The results of the investigation are shown in Tables 5 and 6. According to the AERB, 1.6710^{-4} g/kg/day is the permitted maximum limit for ECR (AERB, 2004). During this investigation, all ECR values were below the permissible limits for water samples. The results of the 116 samples for ECR for mortality and morbidity were calculated for a 70-year-old adult and ranged from 1.002E-05 to 4.19E-05 and 1.010E-06 to 8.92E-05, respectively, with average values of 1.37E-05 and 1.47E-05, respectively. All these ECR values were well below the permissible limit of the AERB.In the present study, the LADD ranged from 0.001 to 2.68, with an average value of 0.3159 for adults; these data are displayed in Tables 5 and 6. The allowable limits of the lifetime average daily dose (LADD) are 4.53 µg/kg/day and 1 µg/kg/day according to the AERB (2004) and WHO (2011), respectively. The obtained postmonsoon LADD values were well below the AERB allowable limit, but 8.62% of the sample values were above the WHO limit.

Table 2: Observed values at the hydro stations

Hydrostation	Lat.	Long.	pH	EC (µS/cm)	TDS ppm	DO mg/L	Al mg/L	Cl mg/L	TH mg/L	CH mg/L	MH mg/L	SO_4 mg/L	F mg/L	U ppb	HCO_3 mg/L
Chichpalli	20.00136	79.47949	5.13	375	250	2.09	344	103.96	212	120	92	63.92	0.3	12.83	9.2
Ajaypur	20.00321	79.49718	5.65	2840	1842	2.19	272	453.85	472	420	52	150	1.6	0.82	5.2
Chiroli	20.01055	79.60836	5.7	1345	870	1.69	180	211.93	476	340	136	54	1.9	35.83	13.6
Khalvaspeth	20.01017	79.60828	5.51	1704	1106	2.5	212	325.89	612	508	104	74	1.3	9.08	10.4
Dahegao	19.97833	79.65044	5.78	741	480	1.99	240	53.98	416	260	156	25	1.3	91.85	15.6
Bejgao	19.98646	79.68993	6	1633	106	2.6	448	155.95	428	380	48	105	0.6	32.27	4.8
Dugala	19.97230	79.70508	5.88	938	609	1.79	304	63.98	412	412	0	27	1.1	88.8	0
Fiskuti	20.01555	79.72163	5.66	710	462	1.59	248	69.97	420	420	0	26	1	9.97	0
Buruchundhi	20.04021	79.72327	5.75	1367	889	1.99	336	139.95	664	620	44	98	0.8	69.48	4.4
Tadala	20.03562	79.67336	5.6	2290	1488	2.09	304	301.9	728	636	92	140	1.3	6.49	9.2
Chitegao	20.10162	79.69780	5.8	808	525	2.08	360	37.98	500	472	28	23	1.5	0.03	2.8
Hirapur	20.11285	79.83896	5.83	1562	1014	2.64	504	197.93	436	372	64	63	1.6	9.2	6.4
Bothali	20.11636	79.81754	5.73	1239	805	2.8	320	123.96	580	528	52	79	2.3	11.09	5.2
Saimara chak	20.19729	79.81061	5.69	1425	924	2.35	368	201.93	604	572	32	46	1.3	63.31	3.2
Pawana chak	20.28552	79.80236	5.56	1417	923	1.53	384	177.94	920	640	280	84	0.5	9.04	28
Dhanora	20.27347	79.72365	5.95	370	242	1.45	216	71.97	688	200	488	1	1.1	9.57	48.8
Karghata	20.31646	79.69891	5.14	541	352	1.69	660	35.98	280	172	108	3	1.8	20	10.8
Sindewahi	20.29218	79.65946	5.66	1152	748	1.89	264	127.96	516	276	240	53	2	45.21	24
Palsgao	20.29846	79.65667	5.6	1704	1107	2.54	316	377.88	840	364	476	56	3.4	38.23	47.6
Chitmara	20.22694	79.77354	5.56	1323	861	1.56	432	115.96	628	304	324	19	2.3	0.03	32.4
Navargao	20.36433	79.58729	5.53	1068	694	1.56	276	129.95	544	276	268	43	1	13.4	26.8
Sawargao	20.41238	79.65227	5.7	1101	714	1.89	264	141.95	644	264	380	59	1.3	39.83	38
Talodhi	20.44603	79.66542	5.64	1321	860	1.76	280	187.94	660	280	380	63	0.8	10.14	38
Nagbhid	20.58150	79.68920	5.78	1596	1035	1.85	324	257.92	616	352	264	99	1.2	0.01	26.4
Mindhala	20.53738	79.71642	5.61	1270	825	1.45	252	283.91	660	272	388	54	2.4	4.51	38.8
Bramhpuri	20.60691	79.85920	6.12	1015	661	2.56	288	173.94	420	164	256	38	0.8	6.93	29.2
Maldongri	20.57757	79.86195	5.62	1309	853	2.48	332	195.93	504	212	292	41	1	0	47.2

Dhamangao	20.46796	79.82911	5.44	1321	858	1.89	260	171.94	732	260	472	43	0.4	71.01	30
Mendki	20.46830	79.82812	5.79	1368	829	1.42	408	159.95	472	172	300	21	1.5	0.01	14.8
Ekara	20.38183	79.79743	5.19	476	311	1.56	160	73.97	272	124	148	4	1	8.68	4
Kothari	19.78826	79.49321	4.7	429	259	1.45	96	53.98	308	268	40	11	2.2	8.67	18
Parsodi	19.55088	79.51307	5.68	2090	1357	2.56	424	173.94	544	364	180	84	0.8	0.01	15.2
Tohgao	19.68336	79.49633	5.66	1188	1188	1.25	416	69.97	648	496	152	42	1.6	0.01	39.2
Wejgao	19.60207	79.50127	5.4	1543	1543	2.56	328	179.94	660	268	392	147	0.8	10.22	5.2
Lathi	19.51391	79.49130	5.17	570	570	1.49	120	51.98	360	308	52	24	1.3	0.02	0.8
Sonapur deshpande	19.54159	79.56361	5.6	1133	1133	2.45	284	129.95	672	644	8	84	1.7	10.4	26.4
Nawegao Chak	20.21761	79.69987	5.63	1863	1863	2.06	380	233.92	732	468	264	119	1.9	0.19	2.8
Adegao	19.60239	79.71480	5.6	1055	1055	2.05	240	39.98	552	524	28	76	0.3	38.93	11.2
Bhangaram Talodhi	19.66196	79.72965	5.82	1478	1478	2.56	400	139.95	664	552	112	99	0.9	49.55	36
Chak Gadholi	19.70469	79.71954	5.58	1418	1418	2.85	352	183.94	792	432	360	49	0.6	0.02	4
Gondpipari CT	19.71680	79.68470	5.48	1689	1689	1.59	364	215.93	600	560	40	82	4.35	55.07	11.6
Chintaldhaba	19.80077	79.63821	5.65	1196	1196	1.96	300	155.95	408	292	116	61	5.1	2.46	1.6
Pombhurna	19.86576	79.63490	5.6	1547	1547	1.94	336	169.94	340	324	16	89	7.85	11.42	10.8
Jam Tukum	19.92269	79.63259	5.65	3260	326	2.09	460	187.94	484	376	108	34	5.75	7.92	21.6
Pipari Deshpande	19.86482	79.76511	5.55	3170	317	2.56	464	59.98	636	420	216	150	9.3	0.78	16
Gatkul	19.79035	79.73468	5.69	2670	267	1.99	412	35.98	480	320	160	150	3.9	0.02	1.2
Rajura	19.77690	79.36502	5.71	1272	1272	1.56	368	125.96	320	308	12	62	15.35	7.14	27.2
Vihirgao	19.72598	79.45766	5.1	1219	1219	2.6	224	169.94	500	228	272	92	12.25	67.5	9.6
Nalpalli	19.67514	79.45317	5.26	738	469	2.58	280	63.98	328	232	96	45	13.7	0.01	67.6
Virur Station	19.64265	79.43100	5.74	991	644	2.56	400	33.98	924	248	676	19	8.95	0.06	26
Tembhurwahi	19.69171	79.35643	5.73	1423	861	2.08	304	135.95	440	180	260	82	12	0.7	31.6
Kapangao	19.77222	79.34174	5.94	2470	1604	2.5	544	293.9	572	256	316	150	5.45	11.08	34.8
Sasti	19.82014	79.32980	5.51	2170	1422	2.46	420	121.96	600	252	348	150	4.9	0	36.8
Ballarshah	19.85209	79.35169	5.56	1036	673	2.17	240	85.97	540	172	368	101	5.15	0.97	4
Babupeth	19.86256	79.34894	4.88	382	271	2.16	100	39.98	336	296	40	28	5.1	4.54	38
Junona	19.92930	79.38683	5.46	1287	844	1.98	304	81.97	736	356	380	56	1.15	0	5.6

Karwa	19.91115	79.38602	5.52	751	487	1.79	260	91.97	548	492	56	20	5.4	1.87	10.8
Ballarshah Tekadi	19.92320	79.31857	5.03	1359	949	1.53	240	173.94	528	420	108	125	7.8	0.3	31.2
Pandhar Pawani	19.74721	79.27447	5.71	1205	783	2.46	288	105.96	516	204	312	108	6.35	16.03	28.8
Bibi	19.76231	79.14222	5.82	988	640	2.86	224	93.97	708	420	288	38	6.8	0.01	9.2
Awalpur	19.77975	79.13397	5.76	873	568	2.06	304	43.98	396	304	92	22.08	5.15	23.5	11.2
Naranda	19.78319	79.05864	5.54	700	488	1.79	280	81.97	424	312	112	20.36	5.75	97.07	3.2
Dhoptala	19.76101	78.99659	6	967	629	1.99	220	61.98	200	168	32	29	4.25	1.2	8.8
Korpana	19.74222	78.98784	5.59	1790	1166	1.56	320	341.89	508	420	88	27.96	4.25	20.98	16
Pardi	19.73584	78.91412	5.84	913	595	2.56	288	27.99	524	364	160	18.64	6.95	35.34	17.2
Umarchira	19.68005	78.90519	5.7	662	430	2.2	256	31.99	416	244	172	18.28	6	7.16	13.2
Durgadi	19.71237	78.86763	5.39	876	570	1.99	280	25.99	456	324	132	12.4	6.5	103.67	22
Kargao khurd	19.68390	79.05155	5.33	879	572	1.99	388	13.99	512	292	220	17.24	4	9.42	11.2
Jivati	19.61510	79.07036	5.7	783	510	1.56	256	29.99	220	108	112	15.2	4.2	9.47	16
Manguda	19.58184	79.00801	5.79	720	466	1.98	336	5.99	392	232	160	12.76	4.45	0.02	0
Wani BK	19.57696	78.99747	6.66	1028	716	2.06	284	91.97	552	356	196	19.68	5.05	10.11	4
Dewalguda	19.60091	79.06269	8.11	550	330	2.35	84	123.96	304	60	244	17.96	4.75	11.86	4.8
Shengao	19.58583	79.14031	5.61	437	269	2.21	136	45.98	144	144	0	12.76	7.4	6.04	24.4
Rahpalli	19.56038	79.13901	5.84	1004	658	2.24	384	125.96	336	296	40	17.96	6.3	7.09	23.6
Bhari	19.50486	79.18319	7.78	955	577	2.1	288	61.98	320	260	60	17.24	1.5	0	32.4
Shedwahi	19.46820	79.19406	5.95	752	488	2.07	348	25.99	180	132	48	15.2	7.05	135.98	62.8
Ranvelli	19.69903	79.30871	5.51	863	523	1.98	288	31.99	356	112	244	15.2	6.7	6.33	16
Visapur	19.88798	79.33008	5.33	951	665	1.82	240	141.95	324	88	236	21.04	9.2	5.94	21.2
Nandgao pode	19.89990	79.30497	5.62	1589	1034	2.03	304	177.94	484	160	324	24.16	2.8	1.56	30
Mana tekadi	19.89981	79.30381	5.56	2400	1551	2.05	368	85.97	760	132	628	198	5.9	13.83	38
Lakhamapur	19.99245	79.26527	5.45	994	713	1.96	296	79.97	368	208	160	30.04	4.95	10.16	9.2
Kiloni	20.15243	79.08996	5.72	2820	1832	1.23	404	453.85	528	316	212	76	3.35	0	22.4
Chalbardi	20.14146	79.05387	5.65	2380	1546	2.01	424	263.91	592	292	300	43.52	6.3	30.21	13.6
Naglon	20.14461	79.01353	5.75	3400	221	1.97	404	527.83	680	300	380	42.84	5.65	0.28	2.8
Kawadsi	20.39122	79.15424	5.72	1765	1149	2.35	440	251.92	392	300	92	16.24	12.15	12.37	14
Wadhada	20.37465	79.15826	5.84	1695	1183	1.36	384	243.92	568	344	224	30.4	6.8	2.2	15.2
Waigao	20.38228	79.20904	5.46	2760	1785	2.26	484	271.91	488	352	136	53.2	6.6	0.63	43.2

Nimdhela	20.41998	79.21153	6.07	1448	940	1.96	408	143.95	216	192	24	21.4	2.8	28.17	32.4
Akola	20.42357	79.19001	5.8	970	633	2.31	296	53.98	268	240	28	16.92	3.15	7.26	1.6
Bothali	20.46249	79.22014	5.8	2670	1732	2.41	536	363.88	404	264	140	46.96	5.65	9.57	10.8
Sonegao	20.50801	79.24696	5.54	2570	1682	1.97	464	361.88	648	496	152	25.56	2.8	23.03	64
Parsodi	20.51187	79.22206	5.82	2210	1512	1.54	312	239.92	700	268	432	55.6	10.85	11.62	0.8
Khadsangi	20.50523	79.26435	5.54	1861	1209	2.3	444	223.93	668	344	324	22.08	5.6	11.82	3.2
Shedgao	20.50707	79.32572	5.59	1228	864	2.14	312	179.94	316	310	16	22.08	4.7	10.54	8.8
Chimur	20.49197	79.37476	5.54	1068	695	2.19	336	113.96	460	352	108	17.6	3.75	0.69	37.2
Kolara	20.40538	79.36829	5.63	5260	342	2.6	396	903.71	1000	360	640	102.96	8.85	5.41	6.4
Neri	20.46699	79.44361	5.62	1182	780	1.35	308	127.96	320	312	8	15.52	10.25	4.42	2.4
Amboli	20.64576	79.48965	5.59	1058	687	1.97	204	143.95	448	416	32	13.44	9.8	3.66	1.2
Bhisi	20.63038	79.40188	6.13	3050	1981	2.79	240	67.97	1000	388	612	51.48	8.7	0.63	26.8
Chargao Khurd	20.36111	79.18265	5.67	1129	726	1.78	344	63.98	392	304	88	17.6	8	16.84	33.6
Arjuni	20.36218	79.18148	5.5	1441	221	2.46	380	273.91	800	428	372	29	10.65	5.43	22.8
Shegon	20.32967	79.14417	5.44	1854	1206	1.97	380	281.91	512	448	64	25.56	12.85	0.31	9.6
Warora	20.22690	79.01031	5.64	1164	758	1.58	460	107.96	224	200	24	19.68	12	0	27.6
Bhadrawati	20.10653	79.12055	5.3	1162	755	2.56	248	169.94	400	388	12	18.28	8.5	0.58	15.2
Lonara	20.06934	79.09795	5.66	5050	326	2.47	632	731.77	640	372	268	105.04	12.55	6.01	7.2
Durgapur	20.00187	79.30308	5.52	2170	1394	1.99	324	317.9	680	344	336	25.2	15.5	0.12	4.8
Khergao	20.02828	79.28093	5.52	2930	1907	1.94	444	403.87	484	256	228	41.44	2	0	26.8
Wandhari	19.98239	79.20995	5.53	1208	783	2.45	404	107.96	324	228	96	19	3.35	1.39	50
Yerur	19.99625	79.19051	5.54	2790	1814	2.13	432	323.89	564	288	276	59.08	1.48	3.42	47.2
Sonegao	19.95890	79.12109	5.49	1373	890	2.26	332	87.97	544	392	152	27.64	1.28	3.34	59.6
Matardei	19.93900	79.11227	5.95	1191	774	2.15	368	79.97	420	348	72	68.2	4.92	0.58	9.2
Ghugus	19.91931	79.11000	5.4	1043	677	2.17	268	113.96	348	300	48	28.32	1.2	12.83	5.2
Nakoda	19.97234	79.17515	5.69	1842	1195	1.98	316	293.9	620	352	268	34.2	1.72	0.82	13.6
Dhanora	19.91398	79.17938	5.62	3600	235	1.97	428	393.87	852	352	500	43.88	1.76	35.83	10.4
Pipari	19.90687	79.20386	5.57	2530	1643	2.3	360	193.93	812	340	472	85.5	1.2	9.08	15.6
Sidur	19.94217	79.21196	5.71	4920	320	2.4	456	293.9	1000	404	596	116.6	4.89	91.85	4.8

Table 3: Values used for calculation of the WQI (Bhutiani *et al.*, 2018)

Parameter	Minimum-maximum value	Standard Value	Ideal value
pH	**4.7-8.11**	**6.5-8.5**	**7**
EC (µS/cm)	**370-5260**	**3000**	**0**
TDS (ppm)	**106-1981**	**500**	**0**
DO (mg/L)	**1.23-2.86**	**5**	**14.6**
Alkalinity(mg/L)	**84-660**	**200**	**0**
TH(mg/L)	**144-1000**	**200**	**0**
CH(mg/L)	**60-644**	**200**	**0**
MH(mg/L)	**8-676**	**100**	**0**
HCO_3(mg/L)	**0.8-67.6**	**600**	**0**
SO_4(mg/L)	**1-198**	**250**	**0**
Cl(mg/L)	**5.99-903.71**	**250**	**0**
F(mg/L)	**0.3-15.5**	**1.5**	**0**
U(ppb)	**0.01-135.98**	**30**	**0**

Table 4: Water quality indices and classes of various hydrostations

Sr. No.	Hydrostation	WQI Value	Class
1.	Chichpalli	27.6301	Good water quality
2.	Ajaypur	86.8860	Very poor water quality
3.	Chiroli	104.0798	Unsuitable for drinking
4.	Khalvaspeth	73.7524	Poor water quality
5.	Dahegao	84.2618	Very poor water quality
6.	Bejgao	48.8395	Good water quality
7.	Dugala	75.7393	Very poor water quality
8.	Fiskuti	61.8337	Poor water quality
9.	Buruchundhi	61.6179	Poor water quality
10.	Tadala	75.8559	Very poor water quality
11.	Chitegao	82.7470	Very poor water quality
12.	Hirapur	87.8357	Very poor water quality
13.	Bothali	116.4644	Unsuitable for drinking
14.	Saimara chak	80.6161	Very poor water quality
15.	Pawana chak	45.1653	Good water quality
16.	Dhanora	72.9950	Poor water quality
17.	Karghata	93.4928	Very poor water quality
18.	Sindewahi	109.5435	Unsuitable for drinking
19.	Palsgao	169.9456	Unsuitable for drinking
20.	Chitmara	118.8379	Unsuitable for drinking
21.	Navargao	64.0633	Poor water quality
22.	Sawargao	81.3981	Very poor water quality
23.	Talodhi	57.2573	Poor water quality
24.	Nagbhid	73.2078	Poor water quality
25.	Mindhala	124.5887	Unsuitable for drinking
26.	Bramhpuri	56.7676	Poor water quality
27.	Maldongri	61.7826	Poor water quality
28.	Dhamangao	45.9601	Good water quality
29.	Mendki	86.1959	Very poor water quality
30.	Ekara	58.3181	Poor water quality
31.	Kothari	104.6748	Unsuitable for drinking
32.	Parsodi	53.4776	Poor water quality
33.	Tohgao	89.6161	Very poor water quality
34.	Wejgao	54.4678	Poor water quality
35.	Lathi	69.7728	Poor water quality
36.	Sonapur deshpande	90.9675	Very poor water quality
37.	Nawegao Chak	102.1828	Unsuitable for drinking
38.	Adegao	35.0986	Good water quality
39.	Bhangaram Talodhi	63.9966	Poor water quality
40.	Chak Gadholi	45.9941	Good water quality
41.	Gondpipari CT	208.6186	Unsuitable for drinking
42.	Chintaldhaba	234.3763	Unsuitable for drinking

43.	Pombhurna	350.1319	Unsuitable for drinking
44.	Jam Tukum	262.4741	Unsuitable for drinking
45.	Pipari Deshpande	411.1263	Unsuitable for drinking
46.	Gatkul	184.3235	Unsuitable for drinking
47.	Rajura	667.0532	Unsuitable for drinking
48.	Vihirgao	538.6308	Unsuitable for drinking
49.	Nalpalli	591.4144	Unsuitable for drinking
50.	Virur Station	402.0643	Unsuitable for drinking
51.	Tembhurwahi	526.3954	Unsuitable for drinking
52.	Kapangao	254.4234	Unsuitable for drinking
53.	Sasti	226.6933	Unsuitable for drinking
54.	Ballarshah	237.2730	Unsuitable for drinking
55.	Babupeth	226.5424	Unsuitable for drinking
56.	Junona	69.3962	Poor water quality
57.	Karwa	246.0375	Unsuitable for drinking
58.	Ballarshah Tekadi	344.5795	Unsuitable for drinking
59.	Pandhar Pawani	289.6649	Unsuitable for drinking
60.	Bibi	307.3705	Unsuitable for drinking
61.	Awalpur	238.6345	Unsuitable for drinking
62.	Naranda	270.8064	Unsuitable for drinking
63.	Dhoptala	198.7871	Unsuitable for drinking
64.	Korpana	201.4041	Unsuitable for drinking
65.	Pardi	316.3791	Unsuitable for drinking
66.	Umarchira	272.4825	Unsuitable for drinking
67.	Durgadi	301.8321	Unsuitable for drinking
68.	Kargao khurd	187.2369	Unsuitable for drinking
69.	Jivati	196.8041	Unsuitable for drinking
70.	Manguda	207.4683	Unsuitable for drinking
71.	Wani BK	241.2595	Unsuitable for drinking
72.	Dewalguda	237.5980	Unsuitable for drinking
73.	Shengao	327.8288	Unsuitable for drinking
74.	Rahpalli	285.3001	Unsuitable for drinking
75.	Bhari	96.6893	Very poor water quality
76.	Shedwahi	330.6584	Unsuitable for drinking
77.	Ranvelli	301.2526	Unsuitable for drinking
78.	Visapur	405.4523	Unsuitable for drinking
79.	Nandgao pode	138.7712	Unsuitable for drinking
80.	Mana tekadi	274.1699	Unsuitable for drinking
81.	Lakhamapur	227.1472	Unsuitable for drinking
82.	Kiloni	164.5687	Unsuitable for drinking
83.	Chalbardi	290.5314	Unsuitable for drinking
84.	Naglon	261.6522	Unsuitable for drinking
85.	Kawadsi	532.4228	Unsuitable for drinking
86.	Wadhada	310.4044	Unsuitable for drinking
87.	Waigao	296.7628	Unsuitable for drinking
88.	Nimdhela	141.8098	Unsuitable for drinking
89.	Akola	151.3937	Unsuitable for drinking
90.	Bothali	259.7564	Unsuitable for drinking
91.	Sonegao	141.0366	Unsuitable for drinking
92.	Parsodi	483.6586	Unsuitable for drinking
93.	Khadsangi	258.0531	Unsuitable for drinking
94.	Shedgao	216.3277	Unsuitable for drinking
95.	Chimur	175.9898	Unsuitable for drinking
96.	Kolara	398.9837	Unsuitable for drinking
97.	Neri	451.1582	Unsuitable for drinking
98.	Amboli	431.1817	Unsuitable for drinking
99.	Bhisi	394.1907	Unsuitable for drinking
100.	Chargao Khurd	358.0595	Unsuitable for drinking
101.	Arjuni	470.1089	Unsuitable for drinking
102.	Shegon	559.6283	Unsuitable for drinking
103.	Warora	524.1276	Unsuitable for drinking

104.	Bhadrawati	372.5630	Unsuitable for drinking
105.	Lonara	551.3920	Unsuitable for drinking
106.	Durgapur	674.5642	Unsuitable for drinking
107.	Khergao	104.6903	Unsuitable for drinking
108.	Wandhari	158.0813	Unsuitable for drinking
109.	Yerur	83.4766	Very poor water quality
110.	Sonegao	72.4299	Poor water quality
111.	Matardei	228.0912	Unsuitable for drinking
112.	Ghugus	67.6882	Poor water quality
113.	Nakoda	94.3253	Very Poor water quality
114.	Dhanora	102.0337	Unsuitable for drinking
115.	Pipari	74.3265	Poor water quality
116.	Sidur	241.1126	Unsuitable for drinking

Table 5: Carcinogenic and noncariogenic risk due to uranium in the postmonsoon season

Sampling Location	*U (ppb)*	*Average Conc. (Bq/L)*	*R Mortality*	*R (Morbidity)*	*ECR (Mortality)*	*ECR (Morbidity)*	*LADD (µg/kg/Day)*	*HQ*	*DE (µSv/Yr)*	*Cumulative Dose (µSv*Lifetime)*
Chichpalli	12.826	0.3206	4.19E-05	6.48E-05	1.343E-05	2.07E-05	0.252	0.0049	7.266E-06	0.000
Ajaypur	0.820	0.0205	4.19E-05	6.48E-05	8.589E-07	1.328E-06	0.016	0.000	4.646E-07	3.252E-05
Chiroli	35.834	0.8959	4.19E-05	6.48E-05	3.753E-05	5.805E-05	0.706	0.013	2.030E-05	0.001
Khalvaspeth	9.080	0.227	4.19E-05	6.48E-05	9.511E-06	1.470E-05	0.179	0.003	5.147E-06	0.000
Dahegao	91.845	2.2961	4.19E-05	6.48E-05	9.620E-05	0.000	1.8106	0.035	5.204E-05	0.003
Bejgao	32.271	0.8068	4.19E-05	6.48E-05	3.380E-05	5.227E-05	0.6362	0.012	1.828E-05	0.001
Dugala	88.799	2.2199	4.19E-05	6.48E-05	9.301E-05	0.00	1.750	0.034	5.031E-05	0.003
Fiskuti	9.973	0.2493	4.19E-05	6.48E-05	1.044E-05	1.615E-05	0.196	0.003	5.650E-06	0.00
Buruchundhi	69.480	1.737	4.19E-05	6.48E-05	7.278E-05	0.000	1.369	0.027	3.937E-05	0.002
Tadala	6.486	0.1621	4.19E-05	6.48E-05	6.794E-06	1.050E-05	0.127	0.002	3.674E-06	0.000
Chitegao	0.0317	0.0007	4.19E-05	6.48E-05	3.320E-08	5.135E-08	0.000	1.243E-05	1.586E-08	1.11E-06
Hirapur	9.203	0.2300	4.19E-05	6.48E-05	9.640E-06	1.490E-05	0.181	0.003	5.215E-06	0.0
Bothali	11.093	0.2773	4.19E-05	6.48E-05	1.161E-05	1.797E-05	0.218	0.004	6.285E-06	0.00
Saimara chak	63.305	1.5826	4.19E-05	6.48E-05	6.631E-05	0.000	1.248	0.024	3.587E-05	0.002
Pawana chak	9.039	0.2259	4.19E-05	6.48E-05	9.468E-06	1.464E-05	0.178	0.003	5.120E-06	0.00
Dhanora	9.573	0.2393	4.19E-05	6.48E-05	1.002E-05	1.550E-05	0.188	0.003	5.424E-06	0.00
Karghata	19.998	0.4999	4.19E-05	6.48E-05	2.094E-05	3.239E-05	0.394	0.007	1.133E-05	0.00
Sindewahi	45.210	1.1302	4.19E-05	6.48E-05	4.735E-05	7.324E-05	0.891	0.017	2.561E-05	0.001
Palsgao	38.228	0.9557	4.19E-05	6.48E-05	4.004E-05	6.192E-05	0.753	0.014	2.166E-05	0.001
Chitmara	0.025	0.0006	4.19E-05	6.48E-05	2.618E-08	4.05E-08	0.000	9.716E-06	1.359E-08	9.519E-07
Navargao	13.399	0.3349	4.19E-05	6.48E-05	1.403E-05	2.170E-05	0.264	0.005	7.591E-06	0.00
Sawargao	39.827	0.9956	4.19E-05	6.48E-05	4.171E-05	6.451E-05	0.785	0.015	2.256E-05	0.001
Talodhi	10.140	0.2535	4.19E-05	6.48E-05	1.062E-05	1.642E-05	0.199	0.003	5.745E-06	0.000
Nagbhid	0.012	0.0003	4.19E-05	6.48E-05	1.257E-08	1.944E-08	0.000	4.663E-06	6.799E-09	4.759E-07
Mindhala	4.506	0.1126	4.19E-05	6.48E-05	4.720E-06	7.299E-06	0.088	0.001	2.552E-06	0.00
Bramhpuri	0.010	0.00025	4.19E-05	6.48E-05	1.047E-08	1.62E-08	0.000	3.886E-06	4.533E-09	3.173E-07
Maldongri	6.929	0.1732	4.19E-05	6.48E-05	7.258E-06	1.122E-05	0.136	0.002	3.925E-06	0.000
Dhamangao	0.001	0.00002	4.19E-05	6.48E-05	1.047E-09	1.62E-09	1.971E-05	3.886E-07	0	0
Mendki	71.0127	1.7753	4.19E-05	6.48E-05	7.438E-05	0.000	1.399	0.027	4.023E-05	0.002
Ekara	0.011	0.00027	4.19E-05	6.48E-05	1.152E-08	1.782E-08	0.000	4.275E-06	4.533E-09	3.173E-07
Kothari	8.682	0.2171	4.19E-05	6.48E-05	9.094E-06	1.406E-05	0.171	0.003	4.918E-06	0.00
Parsodi	8.671	0.2168	4.19E-05	6.48E-05	9.082E-06	1.404E-05	0.170	0.003	4.911E-06	0.00
Tohgao	0.007	0.00017	4.19E-05	6.48E-05	7.332E-09	1.134E-08	0.000	2.720E-06	2.266E-09	1.58E-07
Wejgao	0.006	0.00015	4.19E-05	6.48E-05	6.285E-09	9.72E-09	0.000	2.331E-06	2.266E-09	1.58E-07
Lathi	10.219	0.2555	4.19E-05	6.48E-05	1.070E-05	1.655E-05	0.201	0.003	5.789E-06	0.00
Sonapur deshpande	0.021	0.00052	4.19E-05	6.48E-05	2.199E-08	3.402E-08	0.000	8.161E-06	1.133E-08	7.933E-07
Nawegao Chak	10.400	0.26	4.19E-05	6.48E-05	0.000	0.00	0.205	0.004	5.893E-06	0.00
Adegao	0.185	0.0046	4.19E-05	6.48E-05	1.937E-07	2.997E-07	0.003	7.190E-05	1.042E-07	7.298E-06
Bhangaram Talodhi	38.931	0.9733	4.19E-05	6.48E-05	4.078E-05	6.306E-05	0.767	0.015	2.205E-05	0.001
Chak Gadholi	49.554	1.2389	4.19E-05	6.48E-05	5.190E-05	8.027E-05	0.976	0.019	2.807E-05	0.001
Gondpipari CT	0.024	0.0006	4.19E-05	6.48E-05	2.514E-08	3.888E-08	0.000	9.327E-06	1.359E-08	9.519E-07
Chintaldhaba	55.066	1.3766	4.19E-05	6.48E-05	5.768E-05	8.920E-05	1.085	0.021	3.120E-05	0.002
Pombhurna	2.457	0.0614	4.19E-05	6.48E-05	2.573E-06	3.980E-06	0.048	0.000	1.391E-06	9.742E-05
Jam Tukum	11.421	0.2855	4.19E-05	6.48E-05	1.196E-05	1.850E-05	0.225	0.004	6.471E-06	0.000

Pipari Deshpande	7.920	0.198	4.19E-05	6.48E-05	8.296E-06	1.283E-05	0.156	0.003	4.487E-06	0.000
Gatkul	0.779	0.0194	4.19E-05	6.48E-05	8.160E-07	1.261E-06	0.015	0.000	4.397E-07	3.078E-05
Rajura	0.020	0.0005	4.19E-05	6.48E-05	2.095E-08	3.24E-08	0.000	7.773E-06	1.133E-08	7.933E-07
Vihirgao	7.138	0.1784	4.19E-05	6.48E-05	7.477E-06	1.156E-05	0.140	0.002	4.043E-06	0.000
Nalpalli	67.495	1.6874	4.19E-05	6.48E-05	7.070E-05	0.000	1.330	0.026	3.824E-05	0.002
Virur Station	0.010	0.0002	4.19E-05	6.48E-05	1.047E-08	1.62E-08	0.000	3.886E-06	4.533E-09	3.173E-07
Tembhurwahi	0.060	0.0015	4.19E-05	6.48E-05	6.285E-08	9.72E-08	0.001	2.331E-05	3.399E-08	2.38E-06
Kapangao	0.697	0.0174	4.19E-05	6.48E-05	7.301E-07	1.129E-06	0.013	0.00	3.943E-07	2.760E-05
Sasti	11.081	0.2770	4.19E-05	6.48E-05	1.160E-05	1.795E-05	0.218	0.004	6.280E-06	0.00
Ballarshah	0.001	0.00002	4.19E-05	6.48E-05	1.047E-09	1.62E-09	1.971E-05	3.886E-07	0	0
Babupeth	0.967	0.0242	4.19E-05	6.48E-05	1.012E-06	1.566E-06	0.019	0.000	5.462E-07	3.823E-05
Junona	4.543	0.1136	4.19E-05	6.48E-05	4.758E-06	7.359E-06	0.089	0.001	2.572E-06	0.00
Karwa	0.001	0.00002	4.19E-05	6.48E-05	1.047E-09	1.62E-09	1.97E-05	3.886E-07	0	0
Ballarshah Tekadi	1.874	0.0469	4.19E-05	6.48E-05	1.963E-06	3.035E-06	0.036	0.00	1.060E-06	7.425E-05
Pandhar Pawani	0.295	0.0073	4.19E-05	6.48E-05	3.090E-07	4.779E-07	0.005	0.00	1.654E-07	1.158E-05
Bibi	16.029	0.4007	4.19E-05	6.48E-05	1.679E-05	2.596E-05	0.315	0.006	9.082E-06	0.00
Awalpur	0.011	0.0002	4.19E-05	6.48E-05	1.152E-08	1.782E-08	0.0002	4.275E-06	4.533E-09	3.173E-07
Naranda	23.495	0.5874	4.19E-05	6.48E-05	2.461E-05	3.806E-05	0.463	0.009	1.331E-05	0.00
Dhoptala	97.068	2.4267	4.19E-05	6.48E-05	0.000	0.000	1.913	0.037	5.500E-05	0.003
Korpana	1.197	0.0299	4.19E-05	6.48E-05	1.253E-06	1.939E-06	0.023	0.000	6.777E-07	4.744E-05
Pardi	20.981	0.5245	4.19E-05	6.48E-05	2.197E-05	3.398E-05	0.413	0.008	1.188E-05	0.000
Umarchira	35.335	0.8833	4.19E-05	6.48E-05	3.701E-05	5.724E-05	0.696	0.013	2.002E-05	0.001
Durgadi	7.159	0.1789	4.19E-05	6.48E-05	7.499E-06	1.159E-05	0.141	0.002	4.055E-06	0.00
Kargao khurd	103.674	2.5918	4.19E-05	6.48E-05	0.000	0.000	2.043	0.040	5.874E-05	0.004
Jivati	9.419	0.2355	4.19E-05	6.48E-05	9.866E-06	1.525E-05	0.185	0.003	5.335E-06	0.00
Manguda	9.467	0.2368	4.19E-05	6.48E-05	9.916E-06	1.533E-05	0.186	0.003	5.362E-06	0.000
Wani BK	32.452	0.8113	4.19E-05	6.48E-05	3.399E-05	5.257E-05	0.639	0.01	1.838E-05	0.001
Dewalguda	27.479	0.6869	4.19E-05	6.48E-05	2.878E-05	4.451E-05	0.541	0.010	1.556E-05	0.001
Shengao	0.021	0.0005	4.19E-05	6.48E-05	2.199E-08	3.402E-08	0.000	8.161E-06	1.133E-08	7.933E-07
Rahpalli	10.107	0.2527	4.19E-05	6.48E-05	1.058E-05	1.637E-05	0.199	0.003	5.725E-06	0.00
Bhari	33.954	0.8488	4.19E-05	6.48E-05	3.556E-05	5.500E-05	0.669	0.013	1.923E-05	0.001
Shedwahi	11.862	0.2965	4.19E-05	6.48E-05	1.242E-05	1.921E-05	0.233	0.004	6.720E-06	0.000
Ranvelli	6.041	0.1510	4.19E-05	6.48E-05	6.327E-06	9.786E-06	0.119	0.002	3.422E-06	0.000
Visapur	7.093	0.1773	4.19E-05	6.48E-05	7.429E-06	1.149E-05	0.139	0.002	4.018E-06	0.000
Nandgao pode	0.002	0.00005	4.19E-05	6.48E-05	2.095E-09	3.24E-09	3.942E-05	7.77E-07	0	0
Mana tekadi	135.98	3.3995	4.19E-05	6.48E-05	0.000	0.000	2.680	0.052	7.705E-05	0.005
Lakhamapur	6.329	0.1582	4.19E-05	6.48E-05	6.629E-06	1.025E-05	0.124	0.002	3.585E-06	0.00
Kiloni	5.939	0.1484	4.19E-05	6.48E-05	6.221E-06	9.621E-06	0.117	0.002	3.363E-06	0.00
Chalbardi	1.562	0.0390	4.19E-05	6.48E-05	1.636E-06	2.530E-06	0.030	0.00	8.862E-07	6.203E-05
Naglon	13.834	0.3458	4.19E-05	6.48E-05	1.449E-05	2.241E-05	0.272	0.00	7.838E-06	0.0
Kawadsi	10.159	0.2539	4.19E-05	6.48E-05	1.064E-05	1.645E-05	0.200	0.003	5.755E-06	0.0
Wadhada	0.0001	0.00000	4.19E-05	6.48E-05	1.047E-10	1.62E-10	0	0	0	0
Waigao	30.214	0.7553	4.19E-05	6.48E-05	3.164E-05	4.894E-05	0.595	0.011	1.712E-05	0.00
Nimdhela	18.184	0.4546	4.19E-05	6.48E-05	1.904E-05	2.945E-05	0.358	0.00	1.030E-05	0.00
Akola	0.278	0.0069	4.19E-05	6.48E-05	2.912E-07	4.503E-07	0.005	0.000	1.563E-07	1.09E-05
Bothali	12.374	0.3093	4.19E-05	6.48E-05	1.296E-05	2.004E-05	0.243	0.004	7.010E-06	0.00
Sonegao	2.202	0.0550	4.19E-05	6.48E-05	2.306E-06	3.567E-06	0.043	0.000	1.248E-06	8.74E-05
Parsodi	0.625	0.0156	4.19E-05	6.48E-05	6.546E-07	1.012E-06	0.012	0.000	3.535E-07	2.47E-05
Khadsangi	28.168	0.7042	4.19E-05	6.48E-05	2.950E-05	4.563E-05	0.555	0.010	1.595E-05	0.00
Shedgao	7.260	0.1815	4.19E-05	6.48E-05	7.604E-06	1.176E-05	0.143	0.002	4.113E-06	0.00
Chimur	9.569	0.2392	4.19E-05	6.48E-05	1.002E-05	1.550E-05	0.188	0.003	5.421E-06	0.00
Kolara	23.026	0.5757	4.19E-05	6.48E-05	2.411E-05	3.730E-05	0.453	0.008	1.304E-05	0.00
Neri	11.615	0.2904	4.19E-05	6.48E-05	1.216E-05	1.881E-05	0.229	0.004	6.580E-06	0.0
Amboli	11.815	0.2954	4.19E-05	6.48E-05	1.237E-05	1.914E-05	0.232	0.004	6.693E-06	0.000
Bhisi	9.250	0.2312	4.19E-05	6.48E-05	9.689E-06	0.0000	0.182	0.003	5.240E-06	0.00
Chargao Khurd	10.535	0.26337	4.19E-05	6.48E-05	1.103E-05	1.706E-05	0.207	0.004	5.968E-06	0.00
Arjuni	0.687	0.0171	4.19E-05	6.48E-05	7.196E-07	1.112E-06	0.013	0.00	3.875E-07	2.71E-05
Shegon	5.410	0.1353	4.19E-05	6.48E-05	5.666E-06	8.764E-06	0.106	0.002	3.064E-06	0.00
Warora	4.418	0.1104	4.19E-05	6.48E-05	4.627E-06	7.157E-06	0.087	0.001	2.502E-06	0.00
Bhadrawati	3.663	0.0915	4.19E-05	6.48E-05	3.836E-06	5.934E-06	0.072	0.001	2.073E-06	0.000
Lonara	0.632	0.0158	4.19E-05	6.48E-05	6.620E-07	1.023E-06	0.012	0.000	3.581E-07	2.50E-05
Durgapur	16.844	0.4211	4.19E-05	6.48E-05	1.764E-05	2.728E-05	0.332	0.006	9.544E-06	0.00
Khergao	5.434	0.1359	4.19E-05	6.48E-05	5.692E-06	8.803E-06	0.107	0.002	3.078E-06	0.00

Wandhari	0.305	0.0076	4.19E-05	6.48E-05	3.194E-07	4.941E-07	0.006	0.000	1.722E-07	1.20E-05
Yerur	0.001	0.00002	4.19E-05	6.48E-05	1.047E-09	1.62E-09	1.971E-05	3.886E-07	0	0
Sonegao	0.580	0.0145	4.19E-05	6.48E-05	6.075E-07	9.396E-07	0.011	0.00	3.286E-07	2.30E-05
Matardei	6.011	0.1502	4.19E-05	6.48E-05	6.296E-06	9.737E-06	0.118	0.002	3.404E-06	0.00
Ghugus	0.12	0.003	4.19E-05	6.48E-05	1.257E-07	1.944E-07	0.002	4.663E-05	6.799E-08	4.75E-06
Nakoda	0.002	0.00005	4.19E-05	6.48E-05	2.095E-09	3.24E-09	3.942E-05	7.773E-07	2.266E-09	1.58E-07
Dhanora	1.394	0.0349	4.19E-05	6.48E-05	1.460E-06	2.258E-06	0.027	0.000	7.887E-07	5.52E-05
Pipari	3.416	0.0854	4.19E-05	6.48E-05	3.578E-06	5.533E-06	0.067	0.001	1.933E-06	0.00
Sidur	3.335	0.0834	4.19E-05	6.48E-05	3.494E-06	5.397E-06	0.065	0.001	1.888E-06	0.00

Table 6: Statistical data of parameters (postmonsoon)

Statistical Parameters	*U(ppb)*	*Average ww (Bq/l)*	*Mortality*	*Morbidity*	*LADD*	*HQ*	*DE*	*Cumulative Dose*
Min	0.01	0.000002	1.002E-05	1.010E-06	0.001	0.001	0.030E-05	0.001
Max	135.98	3.3995	4.19E-05	8.92E-05	2.68	0.052	7.71E-05	5.00E-03
Average	16.048	0.401	1.37E-05	1.47E-05	0.3167	0.006	9.09E-06	3.42E-04
Median	7.59	0.18975	7.34E-06	8.78E-06	0.1495	0.002	4.30E-06	0.00E+00

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Conflict of interest

The authors declare that they have no conflicts of interest.

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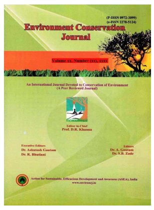

Fatty acid profiling of enterococcal isolates by Fames analysis with reference to antibiotic resistance from clinical samples collected in the Chandrapur region

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ABSTRACT

FAME Analysis is a simple and rapid technique based on Gas Chromatography analysis of bacterial cell membrane. Biochemical lipid profiling of bacterial cell membrane helps to identify bacterial isolates using MIDI Sherlock system. The main objective of present study is rapid and accurate identification of multidrug resistant *Enterococcal* isolates and to study their clinical profile for complicated nosocomial infection from the clinical samples collected at tertiary care center in Chandrapur region. It is essential to identify the causative organism for proper diagnosis and treatment of diseases as enterococcus is fastly emerging pathogen responsible for life threating nosocomial infection and other health hazards.

Introduction

Enterococcus species are a part of the normal flora of humans, but in recent years, they have been identified as opportunistic pathogens that can cause serious health problems. The most common *causes of enterococcal* infection include hospital-acquired infection (Upadhyaya *et al.,* 2009), fecal contamination of drinking water, consumption of unhygienic food, environmental contamination, cross infection, etc. Thus, from a medical standpoint, identifying enterococcal species, which leads to various infections, and determining the prevalence rate of infection caused by bacterial isolates are essential (Fisher *et al.,* 2009). Currently, *Enterococcus species* are characterized by natural resistance to various broad-spectrum antibiotics and by easily acquired resistance to antibiotics. Enterococcus species have rapidly emerged and are of great concern due to the development of antimicrobial resistance (Bekhit *et al.,* 2012). Infections caused by multiantibiotic-resistant strains of *Enterococcus* are more difficult to treat and can be recurrent, highly infectious, chronic and sometimes fatal. In the present study, surveillance was performed at the Tertiary Care Hospital in the Chandrapur District among patients visiting for various diagnostic purposes and treatments; most patient clinical samples were screened for the presence of multidrug-resistant enterococcal isolates for proper diagnosis and treatment of the disease (Arias *et al.,* 2010). The identification of causative organisms is highly essential. Thus, a rapid and reliable method for identifying microorganisms is used to isolate and identify *enterococcal* isolates.

FAME analysis is a technique developed to identify bacterial species more quickly than differential biochemical and media culture testing. In FAME analysis, gas chromatography-accumite ultraviolet spectroscopy was used to determine the importance of bacterial fatty acid methyl esters in identifying and discriminating bacteria based on the fatty acid profile of the bacterial cell wall. The unique configuration of the Sherlock system was designed for the automatic analysis of fatty acid methyl esters via Sherlock pattern recognition software (Morey *et al.,* 2013). A study is therefore essential to identify *enterococcal* isolates that cause various infections

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within a short period of time and to determine the associations of these isolates with potential virulence factors and antimicrobial resistance patterns for appropriate management, diagnostic treatment and treatment.

Materials and Methods

For the present study, urine samples were collected aseptically from the Pathology and Microbiology Department of Government Hospital, Chandrapur. The samples were labeled, sealed properly and transported to the Department of Microbiology, Sardar Patel Mahavidyalaya, Chandrapur, for further processing and isolation. In the Department of Microbiology, Sardar Patel Mahavidyalaya and Chandrapur, the presence of *an enterococcal* isolate from urine samples was detected using microscopic, biochemical and growth methods on differential culture media. Chromogenic UTI media is a differential agar media used to identify the pathogens causing UTI infection. Solid UTI media was inoculated with inoculum from urine samples under aseptic conditions. It was then incubated at 37°C for 24 hr to obtain blue colonies with good growth. A thin smear of the bacterial preparation was mounted on a clean glass slide and subjected to Gram staining. The stained slides were then observed under an oil immersion objective to identify gram-positive cocci that occurred in pairs. Bile Esculine agar is both a differential and selective medium for the isolation of members of the genus *Enterococcus.* The bacterial inoculum was inoculated on sterile slants of bile esculine agar under aseptic conditions and incubated at 37°C for 24 hr. Enterococcus isolates hydrolyze esculine in the presence of bile acid, which turns more than half of the medium to a dark brown color, indicating a positive test. Sheep blood agar is used to grow fastidious microbes that require nutrient-rich environments. It helps to distinguish nonhemolytic, alpha-hemolytic and beta-hemolytic organisms. The bacterial inoculum was inoculated on blood agar, where nonhemolytic, circular, convex colonies with entire margins were observed after 24 hours of incubation.

Table 1: Sample processing for FAME analysis

SN	STEPS	PURPOSE	REAGENTS	PROCEDURE
1	**Harvesting**	**Removal of cells from cultural media for bacterial identification.**	**-**	**A 4 mm loop is used to harvest approximately 40 mg of bacterial cells from III quadrant of culture plate in 13 * 100 culture tube**
2	**Saponification**	**Lysis of cells to liberate fatty acids from the cellular lipids.**	**REAGENT 1 NAOH - 45 gms METHANOL - 150 gms DIST WATER -150 ml**	**Add 1.0 ml Reagent to culture tube and vortex for 5 – 10 sec and keep it in water bath at 100 degree C for 5 min, again vortex for 5 – 10 sec and again keep in water bath for 5 min and then let it cool for 25 min.**
3	**Methylation**	**Formation of Fatty Acid Methyl Ester (FAMEs) which is poorly soluble in aqueous phase.**	**REAGENT 2 6.00 N HCL - 325 ml METHANOL - 275 ml**	**Add 2.0 ml of Reagent 2 and vortex for 5 – 10 sec, now keep it in water bath at 80 degree C for 10 min and cool it rapidly.**
4	**Extraction**	**Transfer of FAMEs from aqueous phase to organic phase for use with Gas Chromatography**	**REAGENT 3 HEXAN -200 ml METHYL TERT-BUTYL ETHER -200 ml**	**Add 1.25 ml of Reagent 3 and stir well for 10 min, remove bottom aqueous phase and save top organic phase**
5	**Base wash**	**Aqueous wash of organic extract prior to chromatography which reduce contamination of injection port line, the column and detector.**	**REAGENT 3 NAOH -10.8 gms DEIONIZED DIST WATER -900 ml**	**Add 3.0 ml of Reagent 4 to organic phase and stir for 5 min and allowed it to rest, Remove 2/3 of top organic phase and transfer it into GC vial, capped it and introduce to GC analyzer.**

FAME analysis

FAME analysis is a technique developed to identify bacterial species more rapidly and easily using the fatty acid profile of the bacterial cell wall. Based on these findings, further work was carried out at Royal Life Science Pvt Ltd., Secanderabad, and Telengana. The sample was aseptically transported and processed for fatty acid profiling and identification of *the enterococcal* isolates. The process of FAME analysis involved harvesting bacterial cells from quadrant III of the culture plate in the late log phase for processing in the culture tube. Various reagents were added to the culture tube containing harvested cells, and proper mixing of the reagents was performed via a vortex machine. In the first reaction, the sodium salt of fatty acids is produced, which then undergoes methylation to form fatty acid methyl esters. A boiling water bath was used to maintain and control the temperature throughout the process. Vigorous mixing via a vortex machine results in the separation of the aqueous and organic phases. The organic phase was then extracted using a base wash. Approximately 2/3 of the organic phase from the culture tube was then transferred to a clean GC sample vial, and the cap was tightly sealed and loaded in an automatic sampler of the MIDI Sherlock system. The Sherlock system is a unique configuration designed for the analysis of fatty acid methyl esters by gas chromatography. The results were compared with those from the stored database of the library using Sherlock pattern recognition software, which helps in the identification of bacterial isolates based on the fatty acid profile (Table 1).

Results and Discussion

The microbial culture obtained from clinical samples (urine) collected at the Tertiary Care Center in the Chandrapur region revealed gram-positive Diplococci, which grow well on UTI Media to produce Blue colonies. The microbial isolates were differentiated by growing them on bile esculine agar, where half of the media turned dark brown in color, and growth on blood agar showed nonhaemolytic, circular, colonies with entire margins. The interpretation of the results for FAME analysis is a visual representation of the result of the library search given after listing the best possible matches and corresponding similarity indices, which are as follows:It is generally found that routine identification of bacterial isolates using conventional methods is common and time consuming. For rapid and accurate identification of bacterial strains, a convenient and precise mechanism is needed. FAME analysis is a standard, sensitive, rapid and rapid method for identifying bacteria. In this technique, screening of bacterial isolates for morphological, physiological, biological and cultural reasons is not needed. The most stable and reproducible cellular fatty acid profile is achieved by regulating growth conditions. A specific temperature and differential media are essential for determining the fatty acid composition of specific bacteria. Most aerobic bacteria grow on TSBA agar, whereas clinical isolates utilize blood agar. Thus, a separate database with standards is established depending on specialized differential media used by specific organisms (Hoffmann *et al.,* 2010). The Sherlock system is based on the similarity index. The fatty acid composition of unknown organisms is numerically related to the fatty acid composition of organisms present in the database library of the Sherlock system (Kunitsky *et al.,* 2006). A sample with a similarity index of 0.500 or greater and a separation of 0.100 is considered to be a close match and highly related. A similarity index between 0.300 and 0.500 and a separation greater than 0.100 were considered good matches but with an atypical strain. A value less than 0.300 indicates that there is no match in the database (Figure 1). A visual representation of the results is given after listing the best possible matches and similarity indices in the form of comparison charts for easy understanding. For each fatty acid, the bar represents a +/- 2 standard deviation window around the entry mean for fatty acid identification with a vertical line (Figure 2). A sample chromatogram is a visual plot that traces the electronic signal generated by the flame ionization indicator as it burns fatty acids eluting from the column (Figure 3).Histogram used for graphical summarization and display of the distribution of process data. A dendrogram provides information about pair matching based on fatty acid composition to show the relatedness of the isolates. (Figure 4). The NJ tree shows the relationship between the organisms, whereas the NJ Rooted Tree

FAME Report generated by using MIDI Sherlock

S.NO	Sample Id	Analysis	Method	Distance	Sim Index	Entry name
1	Sample1	FAME	CLIN6	4.317	0.460	Enterococcus-durans
				5.016	0.350	Enterococcus-cecorum (Streptococcus)
				5.041	0.347	Enterococcus-faecium-GC subgroup A
				5.101	0.338	Enterococcus-hirae-GC subgroup A

Volume: DATA File: E222165.65B Samp Ctr: 5 ID Number: 2619
Type: Samp Bottle: 4 Method: CLIN6
Created: 2/16/2022 3:12:07 PM
Sample ID: 1

RT	Response	Ar/Ht	RFact	ECL	Peak Name	Percent	Comment1	Comment2
1.751	3.245E+8	0.032	----	7.030	SOLVENT PEAK	----	< min rt	
1.997	8584	0.024	----	7.484		----	< min rt	
2.029	12423	0.028	----	7.543		----	< min rt	
2.111	4839	0.025	----	7.694		----	< min rt	
7.758	2916	0.035	0.989	13.999	14:0	5.89	ECL deviates -0.001	Reference 0.002
10.768	4375	0.045	0.954	15.817	Sum In Feature 3	8.53	ECL deviates -0.005	16:1 w7c/16:1 w6c
10.826	1661	0.036	0.953	15.851	Sum In Feature 3	3.24	ECL deviates -0.001	16:1 w6c/16:1 w7c
11.084	14431	0.048	0.951	16.001	16:0	28.05	ECL deviates 0.001	Reference 0.001
14.150	3259	0.044	0.941	17.722	Sum In Feature 5	6.27	ECL deviates 0.002	18:2 w6,9c/18:0 ante
14.238	2150	0.044	0.941	17.771	18:1 w9c	4.14	ECL deviates 0.002	
14.332	18540	0.054	0.941	17.824	Sum In Feature 8	35.66	ECL deviates 0.001	18:1 w7c
14.647	1217	0.041	0.942	17.999	18:0	2.34	ECL deviates -0.001	Reference -0.003
16.253	3023	0.052	0.952	18.905	19:0 cyclo w8c	5.88	ECL deviates 0.003	
----	6036	---	----	----	Summed Feature 3	11.76	16:1 w7c/16:1 w6c	16:1 w6c/16:1 w7c
----	3259	---	----	----	Summed Feature 5	6.27	18:2 w6,9c/18:0 ante	18:0 ante/18:2 w6,9c
----	18540	---	----	----	Summed Feature 8	35.66	18:1 w7c	18:1 w6c

ECL Deviation: 0.002 Reference ECL Shift: 0.002 Number Reference Peaks: 3
Total Response: 51573 Total Named: 51573
Percent Named: 100.00% Total Amount: 48935

Matches:

Library	Sim Index	Entry Name
CLIN6 6.20	0.460	Enterococcus-durans
	0.350	Enterococcus-cecorum (Streptococcus)
	0.347	Enterococcus-faecium-GC subgroup A
	0.338	Enterococcus-hirae-GC subgroup A
	0.315	Enterococcus-casseliflavus
	0.282	Enterococcus-hirae-GC subgroup B

Figure 1: Sample profile information generated by the MIDI Sherlock tool

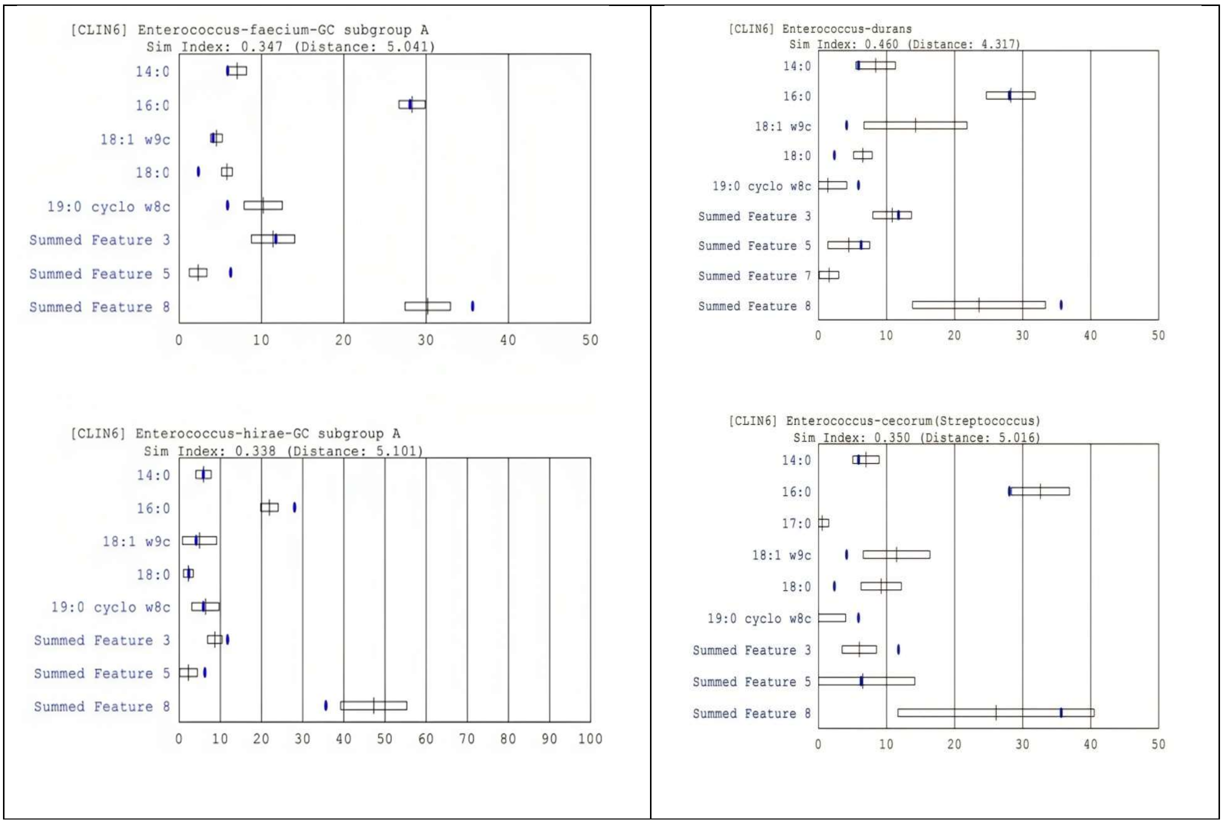


Figure 2: Sim index–comparison chart for bacterial isolates

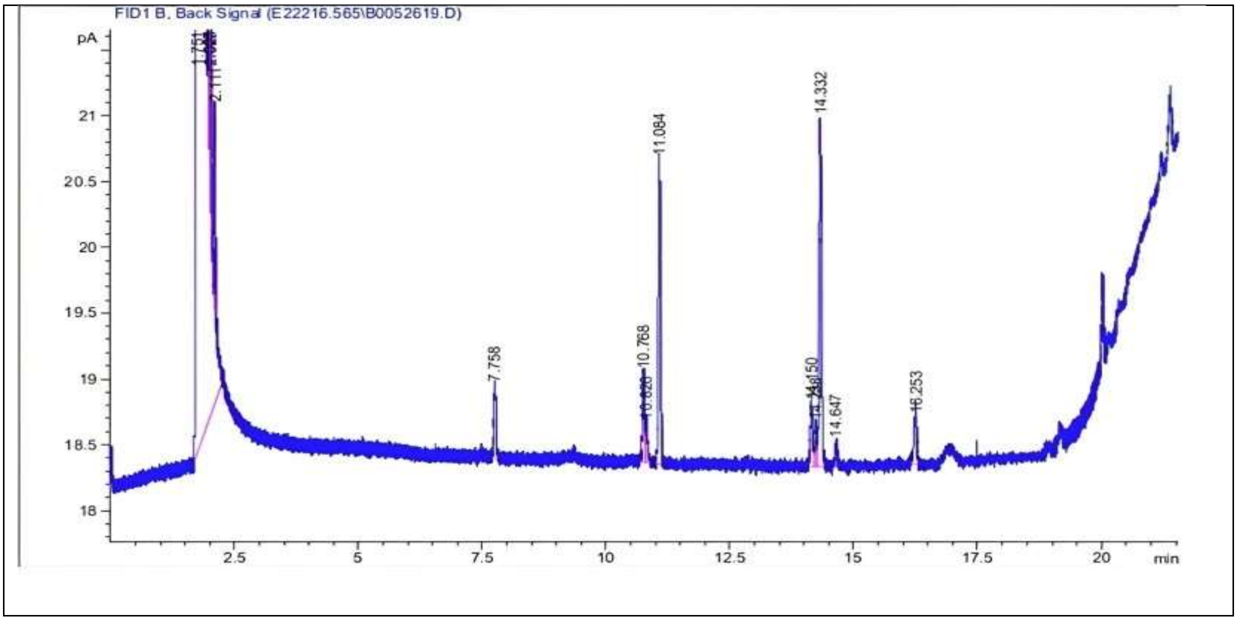
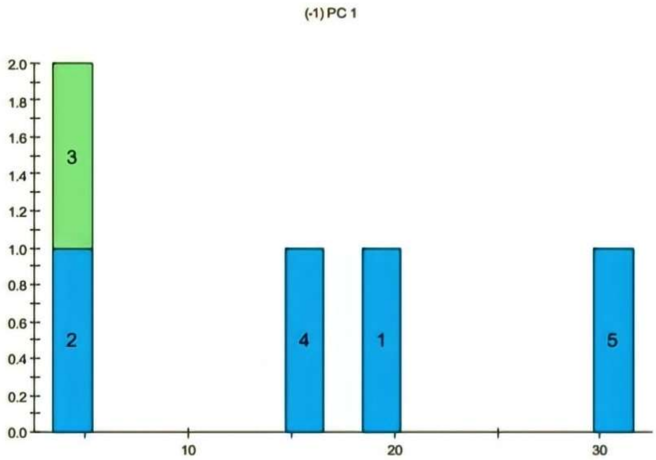


Figure 3: Chtomatogram

HISTOGRAM: Used to graphically summarize and display the distribution of a process data set.

Index	Sel	Volume:Filename#Cntr	Bottle	ID Num	Sample ID
1	Y	DATA:E222165.65B#5	4	2619	1
2	Y	CLIN6 # 173		173	Enterococcus-cecorum(Streptococcus)
3	Y	CLIN6 # 176		176	Enterococcus-durans
4	Y	CLIN6 # 179		179	Enterococcus-faecium-GC subgroup A
5	Y	CLIN6 # 183		183	Enterococcus-hirae-GC subgroup A



DENDROGRAM: Used to produce pair matching based on fatty acids composition.

Index	Sel	Volume:Filename#Cntr	Bottle	ID Num	Sample ID
1	Y	DATA:E222165.65B#5	4	2619	1
2	Y	CLIN6 # 173		173	Enterococcus-cecorum(Streptococcus)
3	Y	CLIN6 # 176		176	Enterococcus-durans
4	Y	CLIN6 # 179		179	Enterococcus-faecium-GC subgroup A
5	Y	CLIN6 # 183		183	Enterococcus-hirae-GC subgroup A

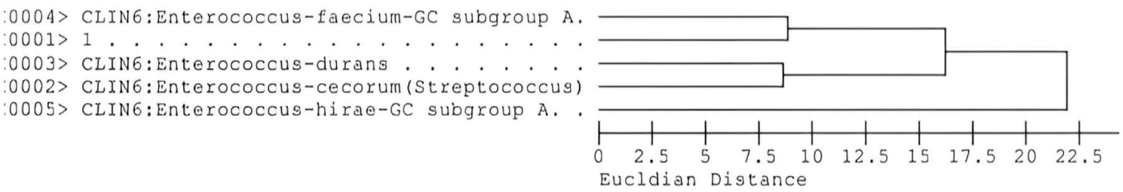
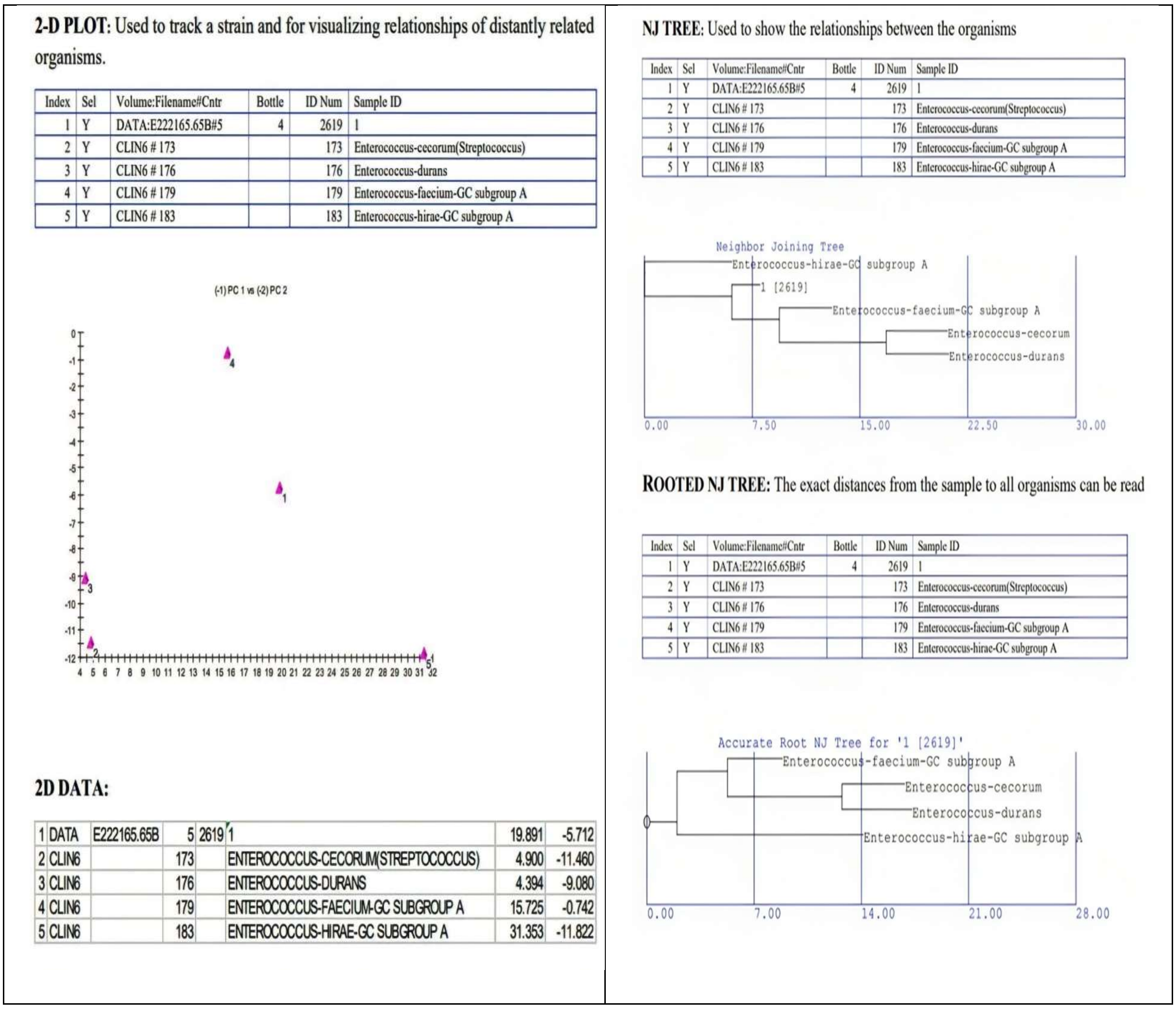


Figure 4: Graphical representation and pair matching of related organisms



Index	Sel	Volume:Filename#Cntr	Bottle	ID Num	Sample ID
1	Y	DATA:E222165.65B#5	4	2619	1
2	Y	CLIN6 # 173		173	Enterococcus-cecorum(Streptococcus)
3	Y	CLIN6 # 176		176	Enterococcus-durans
4	Y	CLIN6 # 179		179	Enterococcus-faecium-GC subgroup A
5	Y	CLIN6 # 183		183	Enterococcus-hirae-GC subgroup A

1	DATA	E222165.65B	5	2619	1	19.891	-5.712
2	CLIN6		173		ENTEROCOCCUS-CECORUM(STREPTOCOCCUS)	4.900	-11.460
3	CLIN6		176		ENTEROCOCCUS-DURANS	4.394	-9.080
4	CLIN6		179		ENTEROCOCCUS-FAECIUM-GC SUBGROUP A	15.725	-0.742
5	CLIN6		183		ENTEROCOCCUS-HIRAE-GC SUBGROUP A	31.353	-11.822

Figure 5: Relationships among distantly related organisms

gives the exact distance of the identified sample from other isolates. A 2D plot was generated to visualize the relationships between distantly related organisms (Figure 5).

Conclusion

The results of the above study showed that the microbial culture obtained from clinical samples collected at the Tertiary Care Center in the Chandrapur region was an enterococcal isolate, which was detected by FAME analysis very rapidly and accurately via the database library of the MIDI Sherlock system. For novel studies, microbiologists should implement this technique for accurate identification of bacterial isolates. There is also a need to upgrade the MIDI Sherlock system by establishing new FAME libraries with chromatographic profiles of additional microorganisms. Based on the fatty acid profile, enterococcal isolates were identified by comparison with TSBA6 and the CLIN6 database library of the MIDI Sherlock system, as microscopic examination revealed gram-positive cocci that grew well on specific media chosen for clinical isolation. If the infective microbial agents are identified accurately and diagnosed properly in a short duration along with the sensitivity pattern for a specific antibiotic, this will help medical practitioners prescribe specific sensitive antibiotics against the causative bacterial isolate. This approach helps in preventing the frequent use of broad-spectrum antibiotics for longer periods, which may cause multiple antibiotic drug resistance in the future.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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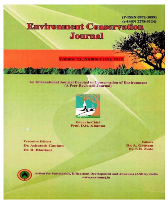

Ethnobotanical significance of several seasonal medicinal plants associated with Amravati suburban habitats

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ABSTRACT

Medicinal plants are integral part of Indian tradition. This traditional practice helped people of India to sustain successfully in this pandemic situation. According to the WHO, approximately 80% of the world's population relies on plant-based preparations for their primary health care needs. The present work was carried to identify the medicinal plants and their ethno botanical use. The area under study is the Amarawati region of state Maharashtra, India. The study was carried out for six months and Ethno botanical data was acquired by conducting interviews using specially designed techniques for collecting ethno pharmacological information. The study reveals the presence of 45 plant species belonging to 22 angiosperm families, which were commonly used for medicinal purposes. Most of time urban developmental activities cause damage to such flora. Whereas the community which is familiar with potential of such species try to utilize them on different alignments in over extend.

Introduction

The present work is focused on the potential value of the indigenous species found in Amravati and its preservation and utilization for bettering society and sustaining the species in nature in the long-term future. With the objective of identifying the species of medicinal importance and sharing it with the edges of society, the ability to improve its availability can be achieved. Amravati is one of the main districts of the state of Maharashtra, India. It is historically rich and the 8th most populated area in the state. It is the second largest growing industrial city in the Vidarbha region, situated 156 km west of Nagpur. New flyovers, roads, rail corridors, malls and other developments are being built to renovate the city. When the literacy ratio is good, life is healthier and more prosperous than it was in the previous era. Owing to this infrastructure, the city remains crowded throughout the year. With the passage of time and increased living standards, people's desirability also increased. To satisfy increasing demands, city occupancy in every possible habitat has increased, and these expansions are interfering with the environment.

Urban habitats and the associated flora

The habitats in the Amarawati region include open wastelands, wetlands, gardens, streams, open layouts, railway yards, old demolished house yards, institutional campuses, play grounds, etc. These areas provide habitat for the survival of several herbaceous as well as shrub species. According to Dhore (1986), the Flora of Amravati District consists of approximately 347 naturalized species associated with the urban environment.

Ethnobotanical significance of the local flora in Amaravati

The term "ethno botany" refers to the study of the relationship between plants and humans, although it also encompasses the study of traditional knowledge about plants. In 2015, Bidak *et al.* (2015) reported that wild plants have a wide variety of ecological, social, and economic values that are important for human well being. Wild plants are the major source of significant non market goods (food,

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medicinal plants, firewood, cork etc.) as well as indirect highvalue nonmarket services (biodiversity conservation, soil protection, water regulation, recreational opportunities) in most societies, especially in developing countries. Himalayas are the home of vast medicinal plants and traditional medical knowledge and local populations are entirely dependent on plants for their primary healthcare needs (Prakash, 2014). Similarly, in the investigated area, the local community also utilizes their associated plant species for general medicinal purposes. According to Abrew *et al.* (2015) settlements of national and transnational migrants who heavily rely on her bal medicine contribute to the consumption of natural products in modern society. Prakash (2014) claims that animals such as nonhuman p rimates, monarch butterflies and sheep also consume that medicinal plant whey is ill. Previous work by Bhogaokar and Devarkar (2012) on the ethano-medicinal significance of Melghat tribes also revealed that local species play important roles in maintaining good health in the associated community. The main thrust of documentation and record making is to acquaint the commons about the diverse nature and importance of local flora for its medicinal value. This approach will aid in curing some ailments with these local medicines, which are readily and freely available.

Materials and Methods

The study was undertaken in different urban habitats, including wastelands, wetlands, gardens, streams, open layouts, railway yards, old demolished house yards, and college campuses and play grounds. Continuous field trips were arranged with the purpose of gathering and identifying various plant species. Throughout August to December 2021, an inventory was meticulously prepared, and photographs of the naturally occurring plant species were captured with the help of a Nikon Coolpix camera. The identification process was conducted using local floras, online literature and verified botanical references, ensuring accuracy and authenticity.

Ethnobotanical data were acquired by conducting interviews using specially designed techniques for collecting ethno-pharmacological field data. To ascertain the medicinal potential of each species, relevant studies and knowledgeable individuals and experts were consulted. Additionally, the ethno botanical

The findings were cross-verified with those of rural Vaidu (traditional healers) to validate their significance. All the data and evidence collected during this process were meticulously analyzed to draw conclusive conclusions.

Table 1: Ethnobotial inventory of plant species

SN	Name of family	No. of Genera	No. of Species
1	**Papilionaceae**	4	8
2	**Asteraceae**	6	7
3	**Euphorbiaceae**	3	6
4	**Amaranthaceae**	3	4

Results and Discussion

With thorough knowledge of its indigenous species and its utilization, India is blessed. The Ayurvedic System & Medicine holds a firm belief in its Indian population. The studies and investigations carried out in the populous city of Amravati beholds prove its command over indigenous culture. According to studies of various ecosystems prevailing in different regions of a city, a wide variety of species (weeds and herbs) are used to treat disparities and illnesses. A total of 40 people with medical backgrounds and knowledge of local medicinal plants from different localities in Amravati were interviewed. The survey data revealed that approximately 45 plant species belonging to 22 angiosperm families were commonly used for medicinal purposes. The largest percentage of medicinal plants obtained belonged to the family Papilionaceae (8 species), followed by Asteraceae (7), Euphorbiaceae (6), Amaranthaceae (4), Nyctaginaceae and Malvaceae, with 2 species. Among the 46 medicinal plants identified, herbs are the most frequently used because they are abundant in fragmented habitats and can be harvested throughout the year. Since leaves are readily available throughout the year and are traditionally thought to have greater medicinal value than other plant parts, they are preferred over other plant parts. Due to their ease of acquisition in large quantities compared to those of other plant parts, stems and roots are also heavily utilized. Additionally, the majority of traditional healers favor using leaves because they are thought to accumulate active ingredients such as alkaloids and tannins from photosynthetic pigments. While working on the same project, Jain *et al.* (2010) and Soman (2014) both reported comparable results.

Table 2: Details of the plant species and their medicinal uses

SN	Scientific Name of Plant	Familiy	Common Name	Medicinal Uses
1	*Acalypha indica*	Euphorbiaceae	Khokli	Leaves are used in Jaundice remedy
2	*Acasia arabica*	Mimosaceae	Babhul	Gum and leaves are used to treat diabetes and skin conditi ons.
3	*Achyranthes aspera*	Amaranthaceae	Aghada	used to treat asthma, bronchitis, dysentery, ear complications and headache,
4	*Aerva lanata*	Amaranthaceae	Kapuri Madhura	Used in the treatment of cough, asthma, and headache and as an antidote for rat poisoning.
5	*Ageratum conyzoides*	Asteraceae	Ghanera	Against dysentery, diarrhea, nematicide and insecticide .
6	*Alternanthera sessilis*	Acanthaceae	Bechkusal	stomach disorders, diarrhea, dysentery and fever
7	*Alysicarpus procumbens*	Papilionaceae	Alyce clover	leaves decoction is given over cough
8	*Amaranthus spinosus*	Amaranthaceae	Kantemath	Fruit ash of is used for Jaundice; root and leaf extract used as a diuretic
9	*Amaranthus viridis*	Amaranthaceae	Math	It is good source of vitamin A, B6, and C. It is diuretic, analgesic, antipyretic, antiulcer antidiabetic and laxative.
10	*Boerhaaviadiffusa*	Nyctaginaceae	Punnarva	Used to cure intestinal colic, kidney disorders, cough, asthma, skin diseases, jaundice& alcoholism,
11	*Calotropis procera*	Asclepiadaceae	Rui	Bark and root bark is used over joint pains, stomach ulcers, constipation and diarrhea
12	*Capsicum annuum*	Solanaceae	Mirchi	Used orally for stomach upset, toothache, poor circulation, fever, and heart disease prevention
13	*Cassia tora*	Caesalpiniaceae	Tarota	Leprosy, ringworm, flatulence, colic dyspepsia, constipati on, cough, bronchitis, and cardiac disorders can all be trea ted with the leaves and seeds.
14	*Cleome viscosa*	Capparaceae	PiwaliTilwan	useful in the treatment of malarial fevers, skin diseases, leprosy, blood diseases, and uterine complaints
15	*Commelinabenghalensis*	Cannaceae	Kena	It is used to treat diarrhea, enteritis, hemorrhoids, urinary t ract infections, and respiratory tract infections.
16	*Corchorus trilocularis*	Tiliaceae	Kaduchunchu	The leaves are used as a plaster to reduce swellings. The seeds are used to treat gripe and nausea
17	*Datura indica*	Solanaceae	Dhotra	It is useful for ulcers, wounds, inflammation, rheumatism, swellings, fever, asthma, bronchitis and toothache.
18	*Eclipta alba*	Asteraceae	Maka	Asthma is treated with plant ash, and burns, diarrhea, and dysentery are treated with plant extract.
19	*Euphorbia geniculata*	Euphorbiaceae	Dudhi	The plant used in ethno medicine for the treatment of constipation, bronchitis and asthma.
20	*Euphorbia hirta,*	Euphorbiaceae	Mothi Dudhi	It is widely used in skin ailments, hypertension and for fevers dengue and malaria.
21	*Euphorbia prostrata*	Euphorbiaceae	Dugdhika	Extract is effective for treatment of bleeding hemorrhoids
22	*Goniogynahirta,*	Papilionaceae	PivliGodhadi	Useful in Diarrhea, Fever, Stomach disorders, Piles, Asthma, Jaundice, Liver disorders Skin diseases, Rheumatism, Diabetes
23	*Indigofera cordifolia*	Papilionaceae	Godhadi, Bechka	Leaves juice is use in toothache, fruits use as a Tonic and treatment of skin diseases
24	*Indigofera linifolia,*	Papilionaceae	Lal Godhadi	The plant is used to treat amenorrhea when combined wit h Euphorbia thymifolia, which is also used to treat febrile eruptions.
25	*Indigofera trifoliata*	Papilionaceae	Barbada	The mucilaginous seeds are used as a nutritive tonic and restorative. They are used to treat rheumatism and leucorrhoea.
26	*Meremiagangetica*	Convolvulaceae	Undirkani	Useful for fever caused by liver enlargement, inflammatio n, cough, headache, neuralgia, rheumatism, diuretic, and k idney diseases.

27	*Mirabilis jalapa*	Nyctaginaceae	Gulbaxi	Leaf juice may be used to treat wounds, the bulbous roots are laxative and increases sexual stamina in men, best for treating animal bites
28	*Oxalis corniculata*	Oxalidaceae	Amboti	This herb, which is the richest source of vitamin C, vitami n B, potassium, and oxalic acid, is used to treat liver and s tomach issues.
29	*Parthenium hesterophorus*	Asteraceae	Ganjargawat	A decoction of the plant is frequently consumed internally as a treatment for a wide range of ailments and partheniu m is applied externally to treat skin conditions.
30	*Pergulariadaemia*	Asclepiadaceae	Utaran	Snake bite, delayed labor, amenorrhea, asthma, and rheu matic swellings are treated with aerial parts of the plant.
31	*Phyllanthus niruri*	Euphorbiaceae	Bhuianwala	The plant is used over urinary tract stones, dysentery, ulcers and swellings
32	*Physalis minima*	Solanaceae	Phataka	In the traditional system of medicine leaf juice used over snakebite, fruits used treatment of spleen disorders
33	*Rhynchosia minima*	Papilionaceae	Kulthi	It is used for abortion, ecbolics, hemorrhoids, diarrhea and dysentery
34	*Ricinus communis*	Euphorbiaceae	Yerandi	Traditionally plant used in abdominal disorders, arthritis, backache, muscle aches, chronic headache, constipation, gallbladder pain, menstrual cramps, rheumatism,
35	*Sida acuta*	Malvaceae	Bala	It is also used as stomachic, diaphoretic antipyretic, astringent, tonic, and in urinary diseases
36	*Sida cordifolia*	Malvaceae	Kharaiti	Bronchial asthma, colds and the flu, chills, lack of sweatin g, headaches, nasal congestion, aching joints and bones, c oughing and wheezing, and edoema are all treated with thi s ayurvedic medicine.
37	*Solanum xanthocarpum,*	Solanaceae	BhuiRingani	It is used in traditional medicine totreat a variety of infecti ous and degenerative diseasesas anantioxidant, anticancer, and anti-HIV agent .
38	*Sonchus asper*	Asteraceae	Mhatara	The plant is quite high in vitamins and minerals, The sap is effective in removing warts, wounds, boils, asthma, bronchitis, gastrointestinal infections and malaria.
39	*Tephrosia purpurea*	Papilionaceae	Sharpunkha	It is used to treat leprosy, ulcers, asthma, tumors, as well as diseases of the liver, spleen, heart, and blood.
40	*Tribulus terrestris*	Menispermaceae	Sarata	In folk medicine, it is used to treatkidney stones, high blo od pressure, and urinary infections as well as for male viri lity and general vitality.The root & fruits are also used as diureticpain reliever, and appetite stimulant.
41	*Tridax procumbens*	Asteraceae	Kambarmodi	High blood pressure, bronchial catarrh, malaria, dysentery, diarrhea, stomach discomfort, headaches, and wound healing are all conditions for which it is used to treat.
42	*Vernonia cinerea*	Asteraceae	Sahdei	The plant is extensively used in stomach aches and for cold, asthma, bronchitis and vaginal discharges.
43	*Vicoa indica,*	Asteraceae	Sonkadi	Whole plant used in abortion; roots are treatment for jaundice, cough, infertility in women, and renal problems.
44	*Vinca rosea*	Apocynaceae	Sadafuli	Alkaloids are helpful in treating cancer, and the plant is used to treat diabetes, high blood pressure, and even as a disinfectant.
45	*Withaniasomnifera*	Solanaceae	Ashwagandha	It is stress-relieving, lowers blood sugar increases muscle strength, improves sexual function in women, and boosts fertility and testosterone in men.
46	*Zizyphus jujuba*	Rhamnaceae	Bor	Used to treat conditions affecting the digestive, cardiovascular, genitourinary, and liver systems as well as illnesses of the respiratory, coughing, and laryngitis systems.

The findings show that the Papilionaceae famil y had the highest percentage of species that are effective at treating various diseases. The Solanaceae and Amaranthaceae families came next. Similar findings have been previously reported by Croitoru (2007), while menpinal pl ants and their customary applications have been researched in communities near the Cherangani hills in western Kenya. Approximately 60 health conditions were categorized into 14 distinct ailment groups based on their usage reports to create a precise ICF (Index of Cultural

Significance). The identified species can be grouped according to their utility into the following categories: digestive system disorders (15 species), respiratory tract infections (18 species), skin diseases (9 species), fever (8 species), excretory system disorders (7 species), cough and cold remedies (10 species), jaundice treatments (5 species), snake bite antidotes (3 species), Tonic herbs (5 species), and cardiac treatments (4 species). The plant parts used for the treatment of various diseases and disorders include roots, leaves, stems, tubers, rhizomes, whole plants, etc. The most widely used parts are (in descending order) leaves (27%) > roots (16%) > fruits (10%) > Seed (10.5%) > bark (8.6%) > whole plant (8%) > flowers (3.8%), other parts of the plant, such as the stem, tuber, latex, gum, bulb, rhizome, pod, and inflorescence.

According to the reports of response, a variety of fa ctors have contributed to the danger of medicinal pl ants in the study area face.

The main threats to important medicinal species are habitat destruction, habitat fragmentation and urbanization, which are followed by overharvesting, ignorance of the value of local wild flora, and expansion of the road system. Most of the population in Amravati, along with the various ecosystems that have been studied, uses a wide variety of plants to treat a variety of illnesses, and locals have fair traditional knowledge of the medicinal properties of these plants.

Figure 1: Photographs of several wild medicinal plants

			
Alternanthera sessalis	***Acalypha indica***	***Ageratum conozoidis***	***Achyranthus aspera***
			
Amaranthus spinosus	***Alysicarpus procumbens***	***Aereva lanata***	***Acasia Arabica***


Amaranthus viridis


Boerhavia diffusa


Calatropis procera


Capsicum anum


Cassia tora


Cleome viscose

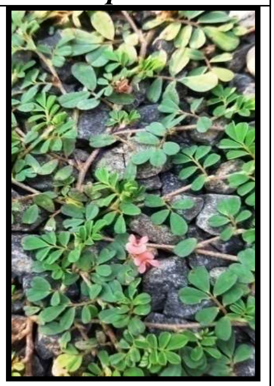

Corchorus trilocularis


Eclipta alba


Euphorbia hirta


Euphorbia prostata


Goniogyna hirta


Indigofera linifolia


Meremia gangetica


Mirabilis jalapa


Oxalis corniculata


Phylanthus niruri

Due to the high cost of Western medicine, a greater proportion of individuals may rely on medicinal herbs. There was little difference in the knowledge of medicinal plants between men and women. In contrast to the findings of a study in Kenya by Bidak *et al*. (2013), there was no preference for one gender over another in terms of the transmission of medicinal plant knowledge from parents to children across Amravati local communities. The informants in the research area looked to be more knowledgeable about medicinal plants, possibly as a result of their increased exposure. The fact that the majority of the species discovered (40) were indigenous and only 5 were foreign illustrates the regional focus of indigenous knowledge about these plant species used for therapeutic purposes.

Local tribes, particularly in the patches of Melghat some vaidus moving through different parts of the city, are blessed and behold command over the medicinal properties of local and indigenous species. Despite the high cost and major side effects of Western/allopathic medicines, much of the population relies on traditional herbs and shrubs for disease ailments. The medicinal properties of these species are poorly understood, and some people mistakenly encounter them as allergic weeds.

Conclusion

The present study revealed that, from the local fauna of Amarawati, approximately 45 plant species belonging to 22 angiosperm families were commonly used for medicinal purposes. The plant parts used for the treatment of various diseases and disorders include the roots, leaves, stems, tubers, rhizomes, and whole plants. In the present era, it is highly important to investigate and gather traditional knowledge about the indigenous species in our areas. The second need is to acquaint the commons and young people about the importance of these species for enhancing conservation and formulating strategies for their preservation. This approach will help to control the spread of offensive or alien species. This approach will help them regain the status of indigenous species and help them retain their status for medicinal purposes. The main threats to important medicinal species are habitat destruction, habitat fragmentation and urbanization, which are followed by overharvesting, the ignorance of the value of the local wild flora and the expansion of the road system.

Conflict of interest

The authors declare that they have no conflicts of interest.

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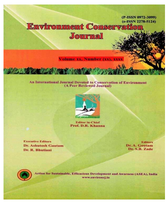

Studies on major insect pests of cotton and farmer perceptions in the Ghugus area of District Chandrapur, Maharashtra, India

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ABSTRACT

A crucial crop in the world, cotton (*Gossypium hirsutum L.*), is frequently harmed by pests and illnesses. Chemical pesticides are frequently effective, but repeated use of these chemicals often results in pests developing greater insecticide resistance, fewer natural enemies, less natural control, and a deteriorated ecosystem. It has been widely used to implement the integrated pest management (IPM) strategy, which heavily emphasizes biological control. The present piece of work was carried out from January 2022 to December 2022 at different sites in the vicinity of the Ghugus area in Chandrapur district. In all, 10 species of insect pests of cotton from 9 families and 3 orders were recorded. The knowledge, perceptions and practices of farmers growing cotton under different pest management regimes were analyzed. The methods used were open and semistructured interviews using questionnaire with groups and individuals. In general, farmers had a poor understanding of the key concepts underlying alternative pest control systems. Pest damage was considered important and farmers were eager to share their knowledge, perceptions and practices in pest management. This study provides the foundation for the creation of a learning platform for future.

Introduction

In India, farmers use all four Gossypium species to cultivate cotton crops. Cotton crops are prone to damage by a number of insect pests. There are more than 166 insects recorded as pests on cotton crops. In India, cotton crops are damaged immediately after the seedling stage by a number of pests, such as grasshoppers, thrips, aphids and jassids. Feeders such as bollworms appear in the crop toward the bud-break stage of the cotton crop and can damage the buds, flowers and bolls. Spiny bollworms, spotted bollworms, American bollworms and pink bollworms were the most common bollworms. Like an insect pest, temperature also affects the growth of cotton plants. Even though cotton is a warm weather crop, the ideal temperature for collecting biomass is thought to be between 20 and 30 degrees Celsius (Zafaretal, 2018). Similarly, a temperature range between 23.5 and 32°C is appropriate for metabolism and the accompanying enzyme to perform at their best. The development and growth of cotton plants are restricted by high temperatures, i.e., temperatures greater than 32°C (Arshad, 2021; Pettigrew, 2007). High temperature and insect pests severely affect cotton production in the region, resulting in poor yields. One of the key constraints to establishing effective pest management approaches for smallholder farmers is the lack of adequate information about pest perceptions and practices in pest management. The diversity of insect pests and the need for integrated pest management with biological control are the main objectives of this study to create an eco-friendly environment. For the development of relevant pest management approaches, an evaluation of farmers' basic socioeconomic characteristics, pest knowledge and perceptions, pest management practices and constraints on effective implementation of pest management practices is needed. Therefore, the present study was undertaken.

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Materials and Methods

The study area is located at 19.93°N 79.13°E, 26 km toward the west of the District Headquarter Chandrapur. In Ghugus, the wet season is hot, warm, and overcast, and the dry season is sweltering and mostly clears. Over the course of the year, the temperature typically varies from 56°F to 112°F and is rarely less than 50°F or greater than 117°F. The area is well known for its coal industries and cement factories. The area within 2 miles of Ghugus is covered by cropland (56%), artificial surfaces (25%), and grassland (11%) within 10 miles by cropland (73%) and within 50 miles by cropland (69%) and trees (11%). The location of the Ghuguscity region is Usgaon (4KM), Shengaon (4KM), Pandharkawada (6KM) and Mursa (9KM). The study was carried out at two villages in the Ghugus area. The insect pest population's data were recorded on the basis of 20 randomly selected plant leaves considering their upper, middle and lower parts. The insect pests were collected in the early morning from 8:00 am to 1:00 pm and photographed with the help of a camera. A total of 60 farmers and their families were surveyed, and the data were collected with the help of basic structured questionnaires, which included age, education, landholding (acres), area under cotton crop (acres), annual income and farming experience.

Figure 1: Location of the study area

Keys for identification

Major insect pests of cotton were identified with the help of the pertinent literature (Raclendran et al*.,* (2018), Pedigo et al*., (*2021).

Results and Discussion

The survey for study was carried out in randomly selected cotton fields in nearby areas of the Ghugus region for a period of 12 months from January 2022 to December 2022. The species of major cotton insect pests investigated are presented in Table 1. During the survey, a total of 10 species from 09 families and 03 orders of insect pests were recorded. Similarly, in the study areas of Punjab, Raza Taqi *et al*. (2019) reported 490 insect species belonging to three classes of 12 orders with 25 families. Fakhra *et al*. (2022) collected 896 insect specimens, 12 of which belonged to 09 families and 05 orders. Cotton farmers mostly employ chemical pesticides, but most producers lack the expertise to apply these chemicals wisely since they do not know much about pest control. Furthermore, locals who work in the pesticide industry typically take advantage of farmers' ignorance to encourage overuse of pesticides above suggested dosages. One of the main factors influencing the use of pesticides is farmers' perceptions about insect pests and how to handle them. According to the research, farmers' incorrect perceptions about the relationship between pesticides and pest control were found to be strongly correlated with excessive pesticide use, which in turn led to the failure of pest management strategies. It is imperative that growers receive IPM education (Shahrajabian, *et al.*, 2020). The socioeconomic characteristics and the respondent profile are shown in Table 2.

Table 1: The species of major cotton insect pests found near the Ghugus area during the investigation

SN	Name of the pests	Scientific Names	Family	Order
[A]	**Borers** American bollworm Pink bollworm Spiny bollworm Spotted bollworm	*Helicoverpa Armigera Pectinophor agossypiella Earias Insulana Earias vittella*	*Noctuidae* *Gelechiidae* *Nolidae* *Nolidae*	Lepidoptera Lepidoptera Lepidoptera Lepidoptera
[B]	**Foliage Feeders** Leaf roller	*Syllleptederrogata*	Pyrilidae	Lepidoptera
[C]	**Sap Feeders** *Aphids* *White fly* *Jassids* *Thrips* *Red cotton bug*	*Aphis gossypii glover Bemisiata baci Amrasca biguttula bigutulla Thrip stabacilinderman Dysderus cingulatus*	*Aphididae Aleyrodidae* *Cicadellidae Thripidae* *Pyrrihocoridae*	*Hemiptera* *Hemiptera* *Hemiptera Thysanoptera* *Hemiptera*

Table 2: Information about the respondents

SN	Profile	Number of farmers	Percent
[1]	**Age**		
	Young age (Up to 30 years)	10	16.67
	Middle age (31 to 50 years)	40	66.67
	Old age (Above 50 years)	10	16.67
[2]	**Education**		
	Illiterate	0	0.00
	Primary school Middle school	5	8.4
	SSC	15	25
	College and above	35	58.34
		5	8.4
[3]	**Land holding (Acres)**		
	2 to 4	10	16.67
	4 to 10	45	75
	10 and above	5	8.4
[4]	**Area under cotton crop (acres)**		
	2 to 4	10	16.67
	4 to 10	45	75
	10 and above	5	8.4
[5]	Annual Income (Rs.)		
	Upto 40,000/-	5	8.4
	40,001 to 80,000/-	10	16.67
	80,001 to 1,20,000/-	15	25
	1,20,001 and above	20	33.34

The majority of cotton growers were in the middle age group (66.67%) and had matriculation-level education (58.34%), landholding size, area under cotton crop in acres (75%), and annual income (33.34%). Similar information about the respondents was recorded by Shambharkar et al. (2018) and Hein Aung Zaw (2023).

Conclusion

Intercropping plays a major role in cotton production. In the cotton intercropping strategy, the pests that are most damaging to the cotton crop will ultimately damage the other crops that are grown inhe cotton field area, through which the minimization of insect pests on the cotton plant canbe controlled. In the present investigation, a total of 10 species of major insect pests from 9 families and 3 orders of cotton were recorded. The diversity of insect pests and the need for integrated pest management with biological control will be the main objectives of this study to create an eco-friendly environment.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Response of gamma irradiation on germination and seedling growth of green gram var. GAM 8

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ABSTRACT

Being a pulse crop, green gram has huge scope in crop improvement in terms of productivity and other yield related parameters. Genetic variability is a preferable option for breeders in breeding programme for varietal development programme and others crop improvement aspect. The present investigation was framed to create the variability in mung bean var. GAM 8 during the seedling period through gamma (γ) irradiation. The significant variation was observed in germination percentage and it was found that dose dependent relationship between the germination rate and dose. Significantly minimum germination percentage (22.38 %) was observed in 700 Gy but optimal lethal dose (LD50) calculated through Probit analysis based on germination percentage was revealed at 540.26 Gy. Data revealed that γ irradiation had significantly reduced the seedling growth parameters such as shoot length (10.05 cm), shoot dry weight (19.68 mg), seedling length (13.90 cm), vigour index I (311.01) and II (509.01) was registered in 700 Gy while minimum root length (3.83 cm) was occurred in 600 Gy γ irradiation. Growth reduction (GR) 50 and 30 with respect to the seedling length was occurred respectively at 1093.79 and 1469.74 Gy. Therefore, this finding as the source of genetic variability would be used in future breeding and crop improvement programme like enhancement of yield potentiality and stress management in mung bean var. GAM 8.

Introduction

Green gram [*Vigna radiata* (L.) Wilczek] is commonly known as mung bean and believed to originated from India and Central Asia. This crop is belonging to the subgenus Ceratotropis in the Leguminosae genus *Vigna* and the family Fabaceae. It is self-pollinated legume crop as the petals enclosed the stamen and stigma. Being a legume crops the crop productivity rate is very low as compared to cereals and it has huge scope in genetic enhancement on account of small genome size (579 Mb) (Arumuganathan and Earle, 1991), short life cycle (around 80 days) and close genetic relationship to other legumes (Kim *et al*., 2015). It is good source of protein (24 %) and these types of proteins are easily digested (Yi-Shen *et al*., 2018). Besides this, iron and folate are abundantly present in mung bean. Recently more emphasis has been initiated using molecular breeding approaches by incorporating next generation sequencing technologies (Kumar *et al*., 2021). Researchers are also approaching to

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increase the productivity of mung bean through various techniques including mutation breeding. However, in mung bean normal breeding methods are not much progress in yield enhancement strategy due to low genetic variability. So far use of several bioagents particularly different species of *Trichoderma* have been advocated for not only in enhancement in seed germination and plant growth promotion in different crops (Kumar *et al*., 2019) but also their capabilities in disease management (Kumar *et al*., 2013; Kumar and Sahu, 2015; Jain *et al*., 2017; Kharte *et al*., 2022), and as biofertilizers (Srivastava *et al*., 2009). However, limited success has been achieved due to inconsistency of these bioagents in natural field conditions. Mutation is one of the oldest techniques used in crop improvement and has been using various physical or chemical forms of mutagens in this technique. X and γ (gamma) rays are the most commonly use physical mutagens in mutation breeding. It has been revealed that yield improvement through γ irradiation in *Brassica juncea* (Khatri *et al*., 2005), trait specific enhancement in mung bean (Tah, 2009) and soybean (Pavadai *et al*., 2010) and even in seed germination and seedling growth variation in chickpea (Shah *et al*.,2008) and mung bean (Bonde *et al*., 2020) was revealed earlier. Selection of mutagen with their desirable dose relay to the effectiveness in mutation and it is the source of variability. Higher the variability in existing germplasms or varieties is an opportunity for plant breeders for healthier and wider selection and formulate advance breeding programme in varietal development policy. Dose or concentration of mutagen varies with varieties; median lethal dose (LD50) is an important tool to fix the concentration of mutagen in mutation breeding. LD50 indicate that optimum dose of mutagen causing 50% of mortality of seed (maximum variability). For examples, LD50 value of mung bean cv. K-851 and Sona was identified as 54.06 and 53.20 kR, respectively (Tah 2006). Beside this, 50% growth reduction (GR50) is also consider by many researchers to be noted down in mutation (Khalil *et al*., 2014). Because LD50 value signified only 50% germination but those germinated plants may or may not reach up to maturity level, survival of mutant is very much necessary for proper generation of M1. Therefore, in mutation breeding programme identification of LD50 along with GR50/GR30 is very meaningful. On this background, the present investigation was framed to create variability at seedling stage and determination of LD and GR50 in mung bean var. GAM 8.

Material and Methods

Green gram variety GAM 8 was released from Anand Agricultural University (AAU), Gujarat in the year 2021 and popularly known as Hira Moti. Seed of said mung bean variety were treated with 9 doses of γ irradiation (*viz*., 200, 250, 300, 350, 400, 450, 500, 600 and 700 Gy) at BARC, Mumbai for the estimation of germination percentage and seeding growth parameters as influenced by γ irradiation. The experiment was conducted in *kharif* 2022 at Medicinal and Aromatic Plants Research Station, AAU, Gujarat. The treated seed along with control were sown in germination tray filled with soil and cocopeat (1:1) in triplet repetitions under the open condition. The final germination percentage was recorded at 9th days after sowing (DAS) and those seeds that attained of 0.5 cm plumule length was considered as germination (Maguire, 1962). The said parameter was calculated using the formula given by Anon., (1999).

$$Germination\ percentage = \frac{Total\ No. of\ seed\ germinated}{Total\ no. of\ seed\ sown} x\ 100$$

Moreover, other seedling parameters which included shoot and root length (cm), shoot and root dry weight (mg), seedling length (cm) and vigour index I and II were also assessed at same period. The VI I and II was calculated by determining germination percentage, length and weight of seedling (Ali *et al*., 2018).

$$Vigour\ index - I = Germination\ percentage\ x\ Seedling\ length$$

$$Vigour\ index - II = Germination\ percentage\ x\ Seedling\ dry\ weight$$

Moreover, from the above germination percentage non-germinated seed was calculated and then it was converted into mortality rate over the control. The corresponding Probit value was generated using Probit table (Robertson *et al*., 2017) and analysed regression in Microsoft excel sheet. LD50 was calculated using regression equation (Y=mx+C) based on the Probit value. For the calculation of GR50 and GR30, seedling length trait was selected and converted by considered control treatment value as 100%. The method of "Analysis of Variance" was Completely Randomized Design (CRD) and treatment means of all characters studied was further compared by means of critical differences at 5% level of significance employing "F test'. The C.V.% was also worked out using standard statistical analysis given by Mungikar, 1997.

Results and Discussion

Germination percentage: In the present investigation, mung bean treated with γ irradiation was showed significant variation in germination and it was decreased with increased in radiation concentration. Significantly maximum germination percent (86.39 %) was registered under the control while it was minimum in 700 Gy (22.38 %) (Table 1-2). The present finding was contrast with an earlier result that germination was increased with increased in mutation dose in mung bean var. (TARM 1) (Bonde *et al*., 2020). They revealed that maximum germination percentage was occurred in 350 Gy (95.9 %) followed by decreased through dose increased. However, in present finding there was gradual decreased in germination and this phenomenon was same with the result of green gram seed mutated with sodium azide (Lavanya *et al*., 2011) and gamma irradiation (Rukesh *et al*., 2017). The higher in dose may inhibit the metabolic function of the cells resulting in damage of certain cells and even of seed embryo. With the fact that there is increase in chromosomal damage with the increase in dose (Kiong *et al*., 2008) resulting its effects on proteins expression and functioning of cells finally preventing in germination (Cheng *et al*., 2010).

Table 1. Effect of γ irradiation on germination and seedling quality parameters of mung bean var. GAM 8

γ Irradiation	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot dry wt. (mg)	Root dry wt. (mg)	Seedling length (cm)	VI I	VI II
0 (Control)	86.39	15.10	4.90	28.67	3.35	20.00	1728.07	2764.33
200 Gy	80.83	12.40	4.70	21.23	3.30	17.10	1381.62	2764.33
250 Gy	80.02	15.77	4.53	27.00	3.07	20.30	1625.00	2406.82
300 Gy	76.50	16.67	4.90	28.23	3.00	21.57	1650.08	2388.43
350 Gy	75.74	15.13	4.43	24.10	3.23	19.57	1481.66	2069.74
400 Gy	69.16	14.83	4.13	28.17	3.30	18.97	1312.71	2178.19
450 Gy	62.24	12.33	4.27	26.87	3.23	16.60	1033.39	1873.00
500 Gy	57.71	10.63	3.87	24.07	3.15	14.50	835.16	1571.46
600 Gy	47.96	10.10	3.83	23.74	3.11	13.93	667.29	1286.29
700 Gy	22.38	10.05	3.85	19.68	3.11	13.90	311.01	509.01
S.Em±	1.79	0.27	0.14	0.46	0.07	0.30	38.41	61.73
C.D. (5 %)	5.28	0.81	0.42	1.36	NS	0.89	113.30	182.10
CV	4.71	3.56	5.74	3.17	3.96	2.96	5.53	5.62

Table 2. Mean square of various germination related parameters of mung bean var. GAM 8

Source of variation	df	Germination	Shoot length	Root length	Shoot dry wt.	Root dry wt.	Seedling length	VI I	VI II
γ irradiation	9	1119.24	18.68	0.52	28.95	0.039	24.17	673991	1258565
Error	20	9.62	0.22	0.06	0.64	0.015	0.27	4425	11431

#df = Degree of freedom

Estimation of median lethal dose (LD50): The LD50 value of γ irradiation of mung bean var. GAM 8 was analysed based on the non-germinated seed through Probit value analysis. The dose response curve based on Probit value were presented in Fig. 1 and its analysis of variance is presented in Table 3. Descriptive statistical data analysis showed statistically significant differences indicated that changes in the independent variables (dose) correlated with shifts in the dependent variable (germination percentage) and relative strength of different independent variables' effects on dependent variable was moderate, r^2 =0.68 (Fig. 2). Mortality percentage based on non-germinated seed and corresponding Probit value are presented in Table 4. According to the regression equation, in this variable the LD50 was occurred at 540.26 Gy [x= (5.0+2.46)/2.73]. So, this γ irradiation dose (540 Gy) was recognised as the optimum dose with respect to 50% germination percentage using this mutagen in mung bean var. GAM 8. However, it was reported that LD50 value varies with species, genotypes, varieties, types of mutagen and nature of treatment and procedure (Parthasarathi *et al.*, 2020). In previous finding showed that LD50 value as 250 Gy of gamma rays in balck gram var. TNAUCo(Bg)6 (Ramya *et al.*, 2014), 450 Gy in green gram var. CO 6 and CO 8 (Rukesh *et al.*, 2017), 375.52 Gy in green gram var. TARM 1 (Bonde *et al.*, 2020), 5888.4 ppm of EMS mutagen in short day Indian onion cv. Bhima Dark Red (Singh, 2021) and in sesame 53.4 % of survival was found in 450 Gy (Kumari *et al.*, 2016).

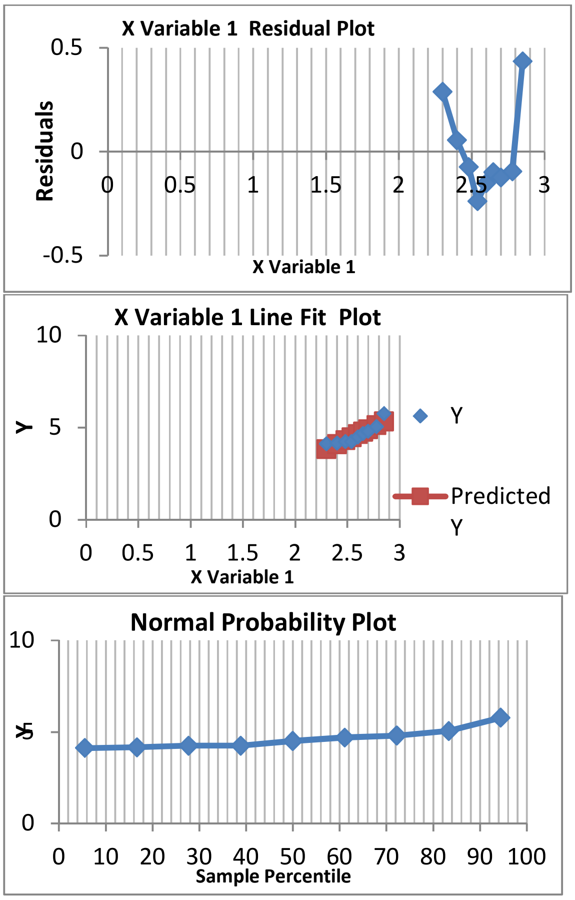

Fig.1. Relation curve of γ irradiation dose and mortality (based on non-germinated seed) of mung bean var. GAM 8 generated through Probit analysis

Seedling parameters: Analysis of variance of all seedling quality parameters analysed in present investigation except root dry weight was found significant effect as affected by γ irradiation in mung bean var. GAM 8 (Table 1). Significantly better seedling quality parameters was found in control. This was indicated that γ irradiation has significant impact on seedling growth in mung bean var. GAM 8. Shoot length was increased from 200 (12.40 cm) to 300 Gy (16.67 cm) dose of γ irradiation followed by gradually decreased. However, root length was found significantly maximum in control as well as in 300 Gy (4.90 cm) and beyond this concentration root length was found started decreased, highest reduction was found in 600 Gy (3.83 cm). Similarly, it was revealed that shoot dry weight was increased with increased in dose up to 300 Gy (28.23 mg) after that it was showed reduction in weight. However, maximum shoot dry weight was occurred in control (28.67 mg). Significantly maximum vigour index I (1728) and II (2764) was registered under the control but maximum reduction was found in 700 Gy over the control. The significant reduction of seedling quality parameters during the germination period owing to γ irradiation have been explained by various researchers in different crops. Earlier it was reported that used of less dose mutagen in mutation treatment showed higher in shoot length in sesame (Kumari *et al.*, 2016). Similarly, Bonde *et al.*, 2020 also showed higher in shoot, root and seedling length over the control. However, in present investigation showed contrast of seedling length as the reduction of length was noted in mutated seedling. It could be resulting that whatever dose used in present studies injured to the meristematic tissue as the outcomes of genetic damage or injury.

Table 3. Analysis of variance of probit analysis

Source of variation	df	SS	MS	F	Significance F
Regression	1	1.90012	1.90012	33.72692	0.000658
Residual	7	0.394369	0.056338		
Total	8	2.294489			

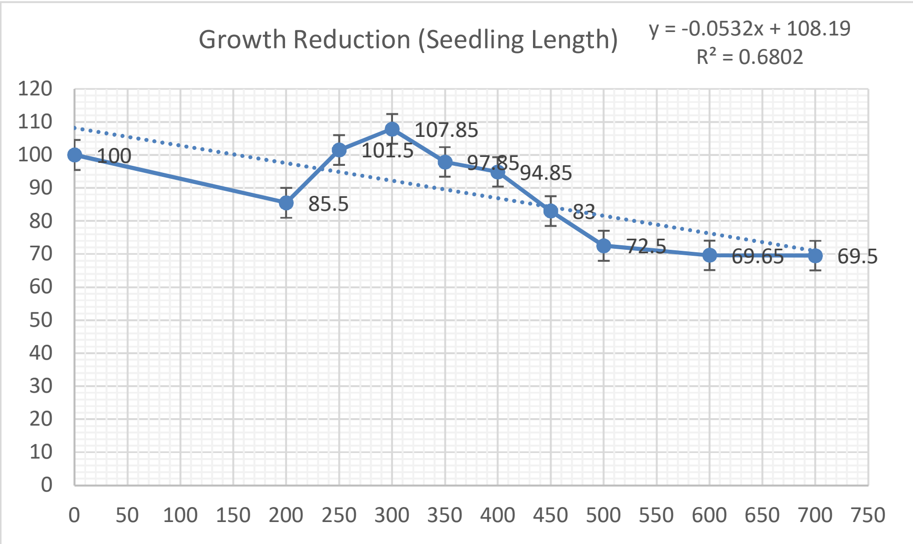

Fig. 2. GR calculation based on converted seedling length value [GR50, x= -58.19/-0.0532 = 1093.79 Gy; GR30, x=1469.74 Gy]

Table 4. Probit analysis for LD50 concentration of γ irradiation on Mung bean var. GAM 8

γ irradiation dose	log10 concentration	Motility percent (Based on non-germinated seed)	Probit value	LD50
200 Gy	2.30	19	4.12	540.26 Gy
250 Gy	2.40	20	4.16	
300 Gy	2.48	24	4.25	
350 Gy	2.54	24	4.25	
400 Gy	2.60	31	4.50	
450 Gy	2.65	38	4.69	
500 Gy	2.70	42	4.80	
600 Gy	2.78	52	5.05	
700 Gy	2.84	78	5.77	

Similar report was also given by Senapati *et al*., 2008 and Ramya *et al*., 2014 in black gram. Further it was showed maximum vigour index (2231.55) in mung bean var. TARM 1 mutated with 450 Gy dose of γ irradiation over the control (1820.72) (Bonde *et al*., 2020). In case of vigour index II declined in various field crops was revealed in spinach, field pea, garden pea and wheat but increased in okra with exposed to γ irradiation (Singh *et al*., 2014). Therefore, response to mutation is directly corresponds to the types of crop and mutagen dose.

Determination of growth reduction (GR50 and GR30) calculation: Variable degree of seedling length response was observed in different γ doses and its converted value by considering control as 100 % is given in Table 5 & 6 and it was used for GR analysis. The maximum reduction of seedling growth length was revealed in 700 Gy (69.5 %).

According to the regression equation shown in Fig. 2 (y =-0.0532x + 108.19), GR50 and GR30 was calculated based on the seedling length and it was occurred at 1093.79 and 1469.74 Gy respectively. The reduction in growth is might be due to the damage of compounds related to the plant metabolism, such as proteins, chlorophyll, auxins and ascorbic acid potentially inhibiting the growth of the seedlings (Kiong *et al*., 2008).

Table 5. Results of probit analysis as the γ irradiation on mung bean var. GAM 8

Parameter	Coefficients
Intercept	-2.45574
X variable 1	2.733549

[Regression Equation, y=mx+c, x= (5.0+2.46)/2.73 =2.73 = Antilog of 2.73 = 540.26 Gy]

Table 6. Determination of GR50 and GR30 based on converted seedling length value by considering control as 100 %

γ irradiation dose	Seedling length (cm)	Converted value
0 (Control)	20.00	100
200 Gy	17.10	85.5
250 Gy	20.30	101.5
300 Gy	21.57	107.85
350 Gy	19.57	97.85
400 Gy	18.97	94.85
450 Gy	16.60	83
500 Gy	14.50	72.5
600 Gy	13.93	69.65
700 Gy	13.90	69.5

Conclusion

From the above results, it can conclude that γ irradiation treatment in mung bean var. GAM 8 had a positive response in creating variation in terms of germination percentage and seedling growth parameters. The LD50 and GR50 with respect to the germination percentage and seedling length was occurred respectively at 540.26 and 1093.79 Gy. Considering all points in mung bean var. GAM 8 could be create variability with γ irradiation and above said doses can be used by breeders to create new mutant line as well as in crop improvement programme of mung bean.

Acknowledgment

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Conflict of interest

The authors declare that they have no conflicts of interest.

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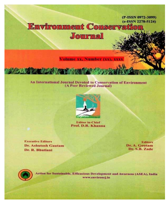

Ambient air quality monitoring of Chandrapur District, Central India

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ABSTRACT

Declining air quality is highly ignored and very common form of degradation of the environment in nations that are both developed and developing. There are several contaminants in the air that have been identified in various studies on air pollution. The crucial parameters of all air pollutants are gaseous and particle pollution. The present study was undertaken to estimate the quality of ambient air in Chandrapur district, Maharashtra state of India. In this paper, an effort has been made to study the standing and trend of Sulphur dioxide (SO_2), Oxides of Nitrogen (NOx), Carbon Monoxide (CO), Ozone (O_3), Ammonia (NH_3), Respirable Suspended Particulate Matter i.e.; PM_{10}, $PM_{2.5}$, toxic pollutants i.e.; lead, arsenic, nickel, benzo [a] pyarene and benzene and hydrocarbons. The results clearly show that, all parameters of ambient air quality monitoring values were some shown slightly below permissible limit. The ambient air quality monitoring data show that the Chandrapur district has substantial air pollution concerns in terms of SO_2, NO_x, PM, and other air pollutants. However, after comparing these values with NAAQS levels, the yearly averages of these air pollutants have been found to be below than the NAAQS levels. However, without effective mitigation measures, the concentrations of these pollutants will rise at quite alarming rate.

Introduction

The level of air pollution has increased rapidly in India during the most recent period (Ahamad *et al.,* 2022; Bhutiani *et al.,* 2021; Ruhela *et al.,* 2022a&b). New Delhi is one of the most polluted cities in the world and is located in northern India. In 2015, 1.09 million deaths related to ambient air pollution were reported in India. The death data were obtained from the Lancet Commission (Kumari and Jain, 2017; Ruhela *et al.,* 2022b). With an increasing population, development activities such as industrialization and urbanization are causing degradation and extreme changes in all characteristics of the environment, namely, the hydrosphere, lithosphere, atmosphere and biosphere, through pollution (Patel *et al.,* 2016). Owing to this characteristic, atmospheric air is a key life-supporting source. A single person respires approximately six liters of air per minute, which is why air quality has become a major concern. The definition of air pollution is defined under the Air (Prevention & Control of Pollution) Act 1981: "it is presence of any solid, liquid or gaseous material in the atmosphere in changeable concentrations as may be pose danger to human or other living creatures or plants or property or environment." The composition of air in the natural atmosphere is steady, but it is being changed due to the discharge of a large quantity of emissions by various industries, vehicles and other sources. This alteration has become a foremost risk to the survival of the species and their habitat. There are 23 major cities in India with a population of more than 1 million people, many of which have air pollution levels higher than those of the World Health Organization (Gupta *et al.,* 2002). Exposure to air pollution has been shown to impair lung development in children (CPCB, 2008), affect cognitive development (Clifford *et al.,* 2016) and

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increase mortality from respiratory infections (Cohen *et al.,* 2017). To stop this astonishing loss of life, we must determine the distinctiveness of lethal particles and gain insight into how this distinctiveness is associated with unfavorable health effects (Manik and Gudadhe, 2020). Rapid industrialization and improper urbanization are causing worsening of the environment and life superiority in budding countries (Gunasekaran *et al.,* 2012). The generated monitoring data can be compared with permissible air quality standards given by the National Ambient Air Quality Monitoring Standard (NAAQMS), and breaching these standards may exacerbate the severity of an area's existing air pollution problems.

In the present study, an effort was made to evaluate the concentrations and trends of particulate matter 10 (PM_{10}), particulate matter 2.5 ($PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO_x), ozone (O_3), ammonia (NH_3), lead (Pb), nickel (Ni), arsenic (As), benzo a payrene (B(a)P) and volatile organic carbons (VOCs), such as methane and nonmethane, in a fast-growing city.

Materials and Methods

Study Area: Air quality evaluation was carried out at fifteen different locations in the Chandrapur district. The ambient air monitoring locations, geographical locations and monitoring heights are given in Table 1 and depicted in Figure 1. All the selected locations were away from any kind of obstacle.

Table 1: Ambient air quality monitoring locations

Sampling Locations	Latitude and Longitude	Height (m) from ground level
Chandrapur	19^0 58' 45.11'' N and 078^0 59' 55.09'' E	7
Mul	20^0 03' 46.71'' N and 079^0 39' 58.65'' E	8
Gondpipari	19^0 43' 08.98'' N and 079^0 41' 19.01'' E	6
Warora	20^0 13' 41.83'' N and 079^0 56' 50.49'' E	5
Bhadrawati	20^0 05' 15.99'' N and 079^0 06' 24.65'' E	5
Chimur	20^0 29' 29.92'' N and 079^0 22' 01.49'' E	6
Bramhapuri	20^0 34' 21.45'' N and 079^0 49' 37.08'' E	9
Nagbhid	20^0 34' 55.31'' N and 079^0 40' 55.86'' E	8
Sindewahi	20^0 17' 03.42'' N and 079^0 39' 17.79'' E	6
Rajura	19^0 46' 33.39'' N and 079^0 21' 34.57'' E	6
Korpana	19^0 44' 12.89" N and 078^0 59' 34.00'' E	6
Saoli	20^0 05' 01.25'' N and 079^0 47' 11.49'' E	5
Ballarpur	19^0 49' 49.04'' N and 079^0 20' 55.71'' E	7
Pombhurna	19^0 52' 39.77'' N and 079^0 37' 52.00'' E	5
Jiwati	19^0 38' 13.11'' N and 079^0 04' 23.89'' E	5

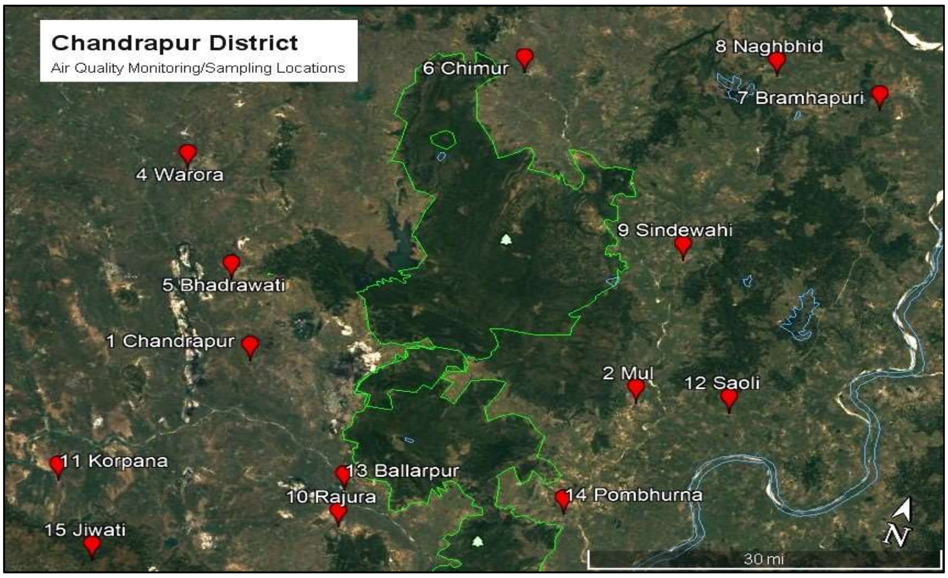

Figure 1: Map showing monitoring locations

Experimental Setup:
The different air parameters considered throughout the present study included $PM_{2.5}$, PM_{10}, CO, SO_2, NO_x, O_3, and NH_3; particulate-associated pollutants such as lead, nickel and arsenic; and B(a)P and VOCs. Similarly, the atmospheric temperature and relative humidity were also recorded. Samples of PM_{10} and $PM_{2.5}$ were collected gravimetrically from the aboveground building station by a respirable dust sampler (RDS) on 8x10 inch fiberglass filter papers at a flow rate of 1.5 m^3/min. After collection, the filter papers were transported to the laboratory for additional analysis, and the dust concentration was computed in $\mu g/m^3$.
The gaseous air pollutants were measured via wet chemical analysis. SO_2, NO_x and NH_3 were estimated as per the Improved West and Gaeke methods (IS 5182 Part 2 Method of Measurement of Air Pollution), Modified Jacob-Honchheiser (Na-Arsenite) (IS 5182 Part 6 Methods for Measurement of Air Pollution), and Indophenol Blue method (Method 401, Air Sampling and Analysis, 3rd Edition), respectively. Ozone was estimated by chemical methods (Method 411, Air Sampling and Analysis, 3 Edition) (Guidelines for the Measurement of Ambient Air Pollutants Volume I). Particulate-associated pollutants such as lead, nickel and arsenic were estimated by digestion with concentrated HNO_3 and analysis via AAS. Hydrocarbon and CO analyses were carried out on an HC-CO analyzer. B(a)P was synthesized by solvent extraction followed by GC analysis. All the methods for ambient air monitoring and analysis were followed according to the National Atomic Maculation Board (CPCB) manual NAAQM (Study on Ambient Air Quality, Respiratory Symptoms and Lung Function of Children in Delhi, 2008).

Statistical methods used:
Statistical analysis is an essential and vital tool in the field of research. The majority of knowledge breakthroughs have occurred as a result of experiments conducted using statistical methodologies (Manik and Gudadhe, 2020) (Yennawar, 1970).

Standard deviation:
The positive square root of the arithmetic mean of the squares of the deviations of the provided observation from the arithmetic mean was used to indicate the standard deviation. It is the most crucial statistic for making statistical forecasts for a variety of research results, and it is the most common measure of dispersion (Manik and Gudadhe, 2020) (Mungikar, 2003).

Results and Discussion

The results for particulate and gaseous pollutants are quantified in Table 2.

Particulate matter (PM): PM consists of many organic and inorganic compounds that vary in size and component characteristics (Cheng & Lin, 2010) (Manik and Gudadhe, 2020). In the present study, the average concentration of $PM_{10 \text{ was}}$ recorded in the range of 42 $\mu g/m^3$-71 $\mu g/m^3$. The highest value was observed at the Chandrapur location due to high vehicular movement and street dust, which is expected to increase the quantity of suspended particulate matter in the atmosphere. In 2017, Patel *et al.* observed a comparable range of PM_{10} concentrations in their investigation conducted in Gujarat (Patel *et al.,* 2017). The average concentration of $PM_{2.5}$ ranged from 28 $\mu g/m^3$ to 36 $\mu g/m^3$. The highest value was observed at Rajura. The concentrations of PM_{10} and $PM_{2.5}$ at all sampling sites were less than the stipulated NAAQS standards (24 hourly PM_{10}-100 $\mu g/m^3$ and $PM_{2.5}$ = 60 $\mu g/m^3$).

Gaseous pollutants: Airborne gaseous pollutants can impair the environment and human health. Gaseous contaminants cause widespread air pollution.

SO_2: The average recorded concentration range of SO_2 was 18 µg/m3–37 $\mu g/m^3$. The lowest average value of SO_2 was found at Bhadrawati, and the highest average value was found at Ballarpur due to various anthropogenic activities, such as the burning of fossil fuels, industrial processes and biomass burning. SO_2 is typically the outcome of industrial activities, and the chief source of SO_2 is anticipated to be motor vehicles, mainly diesel-engined vehicles. The objective of mitigating and reducing SO_2 emissions is achieved by implementing laws that restrict the sulphur content in fuels. The SO_2 concentrations were less than the stipulated CPCB standards (24 hourly SO_2 = 80 $\mu g/m^3$).

NO_x: The average NOx concentration ranged from 30 $\mu g/m^3$- 43 $\mu g/m^3$. The lowest average value of NO_x was found at Rajura, and the highest average value was found at Ballarpur due to human activities, particularly those involving combustion processes. NOx is a collective term for nitrogen oxide gases, including nitric oxide (NO) and nitrogen dioxide (NO_2). Controlling and reducing NO_x emissions involve the use of new and sustainable technology, changes in fuel composition, and regulatory measures. Stricter emission standards and regulations aim to limit the release of nitrogen oxides from various sources. The NO_x concentrations were less than the stipulated standards of the CPCB (NO_x = 80 µg/m^3).

NH_3: The average concentration of NH_3 was in the range of 37 µg/m^3 - 56 µg/m^3. The lowest average value of NH_3 was found in Ballarpur, and the highest average value was found in Chandapur because of the numerous natural processes and activities carried out by humans. Agricultural, industrial, and natural activities all produce ammonia, which is a substance that is made up of nitrogen and hydrogen. Ammonia is a typical byproduct of these processes. The NH_3 concentrations were less than the stipulated standards of CPCB (NH_3 = 100 µg/m^3).

Table 2: Status of ambient air quality {Units: µg/m3, Average24Hours}

Sampling Locations	Average ± Standard Deviation (minimum - maximum)						AQI
	PM_{10}	$PM_{2.5}$	SO_2	NOx	NH_3	O_3	
Chandrapur	71±7 (62-85)	31±7 (21-39)	19±2 (16-22)	35±1 (29-39)	56±6 (43-66)	66±13 (44-72)	71
Mul	52±6 (44-65)	30±5 (22-38)	25±2 (20-25)	42±1 (41-43)	50±5 (40-60)	33±5 (22-44)	53
Gondpipari	49±6 (45-65)	28±5 (21-35)	23±2 (21-25)	41±1 (40-42)	49±5 (42-62)	30±5 (20-41)	51
Warora	49±6 (45-65)	29±5 (23-34)	22±2 (22-24)	42±1 (40-43)	45±5 (41-50)	32±5 (22-45)	53
Bhadrawati	62±9 (49-75)	31±4 (25-39)	18±1 (16-19)	39±1 (38-40)	49±5 (44-61)	62±11 (42-78)	62
Chimur	55±12 (30-72)	32±6 (23-41)	29±2 (25-30)	37±1 (32-45)	49±9 (39-59)	51±12 (25-65)	55
Bramhapuri	45±7 (42-62)	30±8 (20-44)	24±1 (23-25)	33±5 (26-41)	49±6 (43-62)	48±9 (28-60)	50
Nagbhid	56±12 (35-72)	35±6 (22-41)	25±2 (24-31)	40±1 (39-41)	53±10 (40-72)	56±11 (31-65)	58
Sindewahi	48±7 (41-62)	31±7 (21-42)	24±1 (21-25)	33±5 (26-41)	49±6 (43-62)	45±9 (25-65)	61
Rajura	51±12 (31-69)	36±6 (24-42)	29±2 (25-30)	30±1 (29-31)	54±8 (39-74)	57±12 (28-65)	60
Korpana	49±7 (40-61)	30±8 (20-44)	25±2 (21-28)	33±5(26-41)	49±6 (43-62)	47±9 (26-61)	50
Saoli	42±7 (41-62)	31±6 (22-47)	22±2 (23-26)	33±5 (26-41)	49±6 (43-62)	48±9 (32-62)	52
Ballarpur	62 ± 13 (49-80)	35±7 (31-58)	37±9 (29-55)	43±8 (22-56)	37±1 (35-39)	51±10 (39-70)	62
Pombhurna	56±12 (30-72)	32±6 (23-41)	29±2 (25-30)	39±1 (37-40)	53±10 (39-74)	58±12 (29-65)	58
Jiwati	48±7 (44-60)	30±8 (20-44)	26±1 (21-29)	33±5 (26-41)	49±6 (43-62)	48±9 (24-51)	58
NAAQS (2009)	**100**	**60**	**80**	**80**	**100**	**100**	

O_3 and CO: Ozone (O_3) was found in the range of 30 µg/m^3-66 µg/m^{3,} and the range of CO was found to be between 0.42 mg/m^3 and 1.22 mg/m^3. The values of these pollutants were within the stipulated standards of the CPCB. These findings indicated that the levels of gaseous pollutants were somewhat elevated from a health perspective but nevertheless fell below the acceptable limits set by the NAAQM regulations.

Particulate-associated toxic pollutants: Heavy metals are naturally present chemicals, but human actions introduce them in significant amounts into many environmental components. The presence and dispersion of small amounts of metals are determined by the characteristics of the substances released into the air. Elevated levels of heavy metals pose a significant threat to human health. Estimation of heavy metal concentrations in ambient air is essential for environmental academics because of the harmfulness of heavy metals to humans. Some heavy metals, such as Cr, As, Cd and Ni, have been listed as carcinogens. Additionally, these heavy metals in the atmosphere can accumulate in several plants and animals and may pass through the human food chain (Suvarapu and Baek, 2017). Pb, Ni and As are naturally found in nature and in manufactured products (Gudadhe *et al.,* 2012). The average concentrations of these toxic pollutants ranged from 0.05 µg/m^3-0.18 µg/m^3 and 5.9 ng/m^3-8.9 ng/m^3 for Pb and Ni, respectively, whereas As was not detectable at any of the other locations. All these pollutants were found within the NAAQS stipulated standards. The results are listed in Table 3.

Levels of hydrocarbons: Methane and nonmethane hydrocarbons (MHCs and NMHCs) are the key organic pollutants and ozone (O_3) pioneers in the atmosphere (Poisson *et al.,* 2000) and can considerably affect atmospheric photochemical interactions and human health (Atkinson, 2000). The

Table 3: Levels of particulate-associated toxic pollutants

Sampling Locations	Pb	As	Ni	BaP	CO	Benzene	N-CH4	CH4	HCs
	Particulate associated pollutants				Volatile Organic Pollutants				
Chandrapur	0.14	ND	8.9	0.06	0.42	1.13	0.44	1.33	1.45
Mul	0.08	ND	7.2	0.12	0.81	1.10	0.49	0.98	1.00
Gondpipari	0.09	ND	7.9	0.07	0.83	0.37	0.84	0.79	1.13
Warora	0.08	ND	8.5	0.06	0.75	1.00	0.15	0.30	0.69
Bhadrawati	0.09	ND	7.1	0.16	0.49	0.89	0.45	0.82	1.05
Chimur	0.06	ND	7.5	0.06	0.82	0.20	0.15	1.29	1.21
Bramhapuri	0.07	ND	7.4	0.11	0.65	0.84	0.58	0.88	1.25
Nagbhid	0.05	ND	7.0	0.09	0.89	0.55	0.25	1.05	0.87
Sindewahi	0.18	ND	7.1	0.08	1.22	0.22	0.79	0.79	0.99
Rajura	0.07	ND	6.8	0.09	0.98	0.87	0.55	0.65	1.43
Korpana	0.08	ND	6.2	0.10	0.87	1.05	0.39	1.13	1.31
Saoli	0.09	ND	5.9	0.07	0.79	0.89	0.95	0.77	0.68
Ballarpur	0.08	ND	6.2	0.09	0.88	0.59	0.93	1.01	1.72
Pombhurna	0.06	ND	7.0	0.13	0.93	0.87	0.47	0.85	1.59
Jiwati	0.10	ND	6.9	0.08	1.14	0.88	0.30	0.65	1.31
NAAQS (2009)	**1**	**6**	**20**	**1**	**04**	**05**	**03-10**		

Sources of hydrocarbons in urban air are usually led by anthropogenic discharge, including liquefied petroleum gas (LPG) leakage, solvent usage and vehicular releases (Barletta *et al.,* 2005; Tang *et al.,* 2007; Duan *et al.,* 2008). The average concentration of total hydrocarbons was in the range of 0.68 ppm – 1.72 ppm. The concentrations of BaP and benzene were also found to be in the range of 0.06 ng/m3–0.16 ng/m^3 and 0.20 µg/m3–1.13 µg/$m^{3,}$ respectively. The levels of HCs, BaP, and benzene were within the stipulated NAAQS standards. The results are quantified in Table 3.

Conclusion
All the ambient air quality monitoring parameters were less than the stipulated NAAQM standard. However, due to the increase in industrial activities, urbanization, and pollution due to vehicles, there is a boost in A high pollution level may pose a danger to the health of people residing in those particular areas. Due to the risk of health hazards, it is essential to control the increasing concentration of air pollutants. This is the time when good plantations and large trees and green belts were planted in cities or in open spaces in cities to preserve the health of common peoples and curtail atmospheric pollution.

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Conflict of interest
The authors declare that they have no conflicts of interest.

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Effect of calcium and magnesium nutrition on vegetative growth and tuber yield of potato (*Solanum tuberosum*)

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ABSTRACT

A field experiment was conducted to investigate the effect of calcium nitrate and magnesium sulfate on the growth and tuber yield in potato (*Solanum tuberosum* L). Experiment was carried out in split-plot design comprising of nine calcium nitrate and magnesium sulfate treatments i.e. T_1- $Ca(NO_3)_2$ @ 0.5%, T_2- $Ca(NO_3)_2$ @ 1%, T_3- $Ca(NO_3)_2$ @ 2%, T_4- $MgSO_4$ @ 0.5%, T_5- $MgSO_4$ @ 1%, T_6- $MgSO_4$ @ 2%, T_7- $Ca(NO_3)_2$ @ 1% + $MgSO_4$ @ 1%, T_8- $Ca(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%, T_9- Control on two potato varieties i.e. Kufri Jyoti and Kufri Chandramukhi. Data collected on different parameters were analyzed using CPCS1 software. Among all the calcium nitrate and magnesium sulfate treatments, application of $Ca(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% was found to be the best for most of the parameters studied and between the varieties Kufri Jyoti was found highly significant for the different parameters under study. Hence it can be concluded that commercial cultivation of potato in the central region of Punjab can be successfully supplemented with application of $Ca(NO_3)_2$ + $MgSO_4$ and variety Kufri Jyoti.

Introduction

Potato (*Solanum tuberosum* L.) is a widely grown tuber crop all over the world. It belongs to the family Solanaceae and had originated in Peru, South America. It is the fifth most important crop around the world after wheat, corn, rice and sugarcane (Mann, 2011). Next to cereals, potato is the only crop which could supplement the need for the food of the country (Das, 2000). It is a tetraploid crop containing all essential food ingredients, which are required to maintain proper health and considered to be the main source of starch and carbohydrates. Potato is the balanced food containing less energy but considered to be the rich source of starch, vitamin C, folate, vitamin B6, and antioxidants such as flavonoids, phenolic acids, carotenoids and a substantial amount of protein (Mehdi *et al.* 2008). The average composition of potato tuber per 100g edible portion is 79.25g moisture, 2.05g protein, 0.09g fat, 17.49g carbohydrates, 77 kcal energy, 12mg calcium, 57mg phosphorus, 0.81mg iron, 24µg carotene, 0.081mg thiamine, 0.032mg riboflavin, and 19.7mg vitamin-C. Potato cultivation is highly cost-intensive due to many dependencies on fertilizers as reported by Nandekar *et al.* (2006) that nutritional requirement increases with a higher bulking rate as in potato. Production of potato is also affected by certain nutritional deficiencies when cultivated on sandy soils which are low in certain nutrients such as calcium and magnesium. Potatoes are more sensitive to calcium deficiency than many other crops because calcium as an essential macronutrient plays a great role in maintaining cell wall and cell membrane structure in the potato. Calcium performs this function of maintenance by stable linking the polar head groups and pectic acid fractions of the cell wall by stable reversible

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linkages. So supplement the crop with calcium is beneficial in commercial production of potato. Simmons *et al*. (1988) reported that calcium treatments increased the yield of prime sized tubers along with an increase in periderm calcium concentration. Whereas, Locascio *et al.* (1992) reported that tuber yields were increased from 29.8 to 31.6 tons per hectare with the application of calcium-based fertilizers. Adequate amounts of calcium help in improving skin color of red potatoes. Deficient supply of calcium can result in abnormal growth like hollow heart and internal brown spot. It has been reported that the incidence of necrosis and internal rust spot is also reduced by calcium (Clarkson, 1984). An adequate supply of calcium increases potato`s resistance to soft rot during storage and have also potential to increase the seed potatoes performance. Another important nutrient element in potato cultivation is magnesium as in some cases it has been found that severe magnesium deficiency can reduce the yield of tubers up to 15%. Foliar sprays of magnesium can be very effective during dry conditions of soil which can otherwise restrict the uptake. Uptake of magnesium is dependent upon the exchange capacity of the soil and its balance with other cations like potassium. The high concentration of potassium can also cause magnesium deficiency; in such cases the foliar application of magnesium is also recommended. With severe susceptibility to magnesium deficiency, it is essential to include magnesium in the balanced fertilizer programs. Application of calcium in potato has been reported to reduce the input of fungicides, decrease internal necrosis, increase yield, storage life, tuber weight, size, and quality. Calcium also promotes plant growth and root development as it plays part in cell division and root elongation (Iiyama *et al.* 1994). During the stress, calcium helps the plants in resisting them or to adapt the stress by inducing the signal chain (Kudla *et al.* 2010).

Material and Methods

A field experiment was conducted to study the effect of calcium nitrate and magnesium sulfate on growth, tuber yield and late blight (*Phytophthora infestans*) incidence in potato (*Solanum tuberosum* L.). The experiment was laid out during rabi 2017-18 under irrigated condition, at the research farm of Lovely Professional University Phagwara. The experiment was carried out in split plot design with three replications. The experiments had eighteen treatment combinations comprised of nine calcium and magnesium levels i.e. Ca $(NO_3)_2$ @ 0.5% (T_1), Ca $(NO_3)_2$ @ 1% (T_2), Ca $(NO_3)_2$ @ 2% (T_3), $MgSO_4$ @ 0.5% (T_4), $MgSO_4$ @ 1% (T_5), $MgSO_4$ @ 2% (T_6), Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% (T_7), Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% (T_8), control (T_9) and two varieties i.e. Kufri Jyoti (V_1) and Kufri Chandramukhi (V_2). Sprouted seed tubers of potato were dipped before planting in the solution of Dithane M-45 @ 2.5 gm/litre for 20 minutes in a tray to avoid any internal and external fungal infection. Potato seed tubers were taken out 9 days before planting from the cold storage and kept in the shed to accelerate the sprouting of the tubers. The treated tubers were planted on ridges of 60 cm apart with a spacing of 20 cm. The calcium and magnesium water-soluble forms i.e. calcium nitrate and magnesium sulfate were applied as a foliar spray with first spray at 40 DAS followed by two sprays at an interval of 10 days. Different growth and yield attributes were recorded at specific time.

Results and Discussion

Plant height: The plant height was measured in centimetre from ground level to the top of the plant at 75 DAS. Plant height was measured through a centimetre scale and recorded. Five uniform plants were randomly selected and tagged to record the observation. Among the different treatments, calcium nitrate treatments had a more pronounced influence on the plant height as compared to magnesium sulfate treatments. However, combined calcium nitrate and magnesium sulfate treatments i.e. T_7 and T_8 produced significantly taller plants over the alone calcium and magnesium treatments. The highest plant height was observed in T_7 (43.65 cm) i.e. combination of Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1%, which was significantly at par with T_8 (43.10 cm) i.e. Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%. Whereas, the shortest plants (28.60 cm) were produced under the T_9 (control) (table1). Among the varieties, V_1 (Kufri Jyoti) resulted in the maximum plant height (36.45cm) in comparison to V_2(Kufri Chandramukhi) (34.50cm) which showed a 5.65% increase in height over the latter. Significant results were also observed for plant height among the interaction between treatments and varieties.

Interaction between them showed that V_1T_7 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% performed better and resulted in the highest plant height (47.67cm) and found to be significantly at par with V_1T_8 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%). Likewise, V_2T_8 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%) was at par with V_2T_7 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1%) and V_1T_2 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 1%). Similarly, V_1T_3 was at par with V_2T_2 and V_2T_3. However, V_1T_9 i.e. (Kufri Jyoti under control) resulted in the lowest plant height (27.27 cm). The higher plant height might be due to better nutrient absorption and higher rates of photosynthesis. Seifu (2017) observed a significant interaction between calcium nutrients and potato varieties for plant height and noticed that due to the application of $CaNO_3$ and $CaCl_2$ at 15 g per plant resulted in 45% higher plant height than the control. The difference in plant height among the varieties may be attributed to genetic differences which are in accordance with the finding of Verma *et al.* (2013) and Gupta *et al*. (2017).

Number of leaves per plant: Leaves are associated with the interception and utilization of solar radiation and consequently effect dry matter accumulation and ultimately the tuber yield. The significant effect of treatments, varieties, and interaction between treatments and varieties on the number of leaves per plant. Among the different treatments, the lowest number of leaves per plant was observed under control (37.23), whereas the highest number of leaves per plant (44.85) was achieved by T_7 i.e. Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% which was significantly similar to T_8 i.e. Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% (44.73). However, Ca $(NO_3)_2$ @ 0.5% i.e. T_1 and $MgSO_4$ @ 0.5% i.e. T_4 produced a significantly lower number of leaves per plant and were significantly at par with one another (table1). The significant parity was also observed among the T_2, T_5, and T_6 treatments combinations which were significantly lower than the T_3 treatment. Among the varieties, V_1 (Kufri Jyoti) resulted in the maximum number of leaves per plant (43.52) in comparison to V_2 (Kufri Chandramukhi) (39.94) which showed 8.96% increase in the number of leaves per plant over the latter. Significant results were also observed for a number of leaves per plant among the interaction between treatments and varieties. Interaction between different treatments and varieties showed that V_1T_7 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% each performs better and resulted in the highest number of leaves per plant (47.27) and found significantly at par with V_1 T_8 (47.20) i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%. Treatment V_1T_2 was also found significantly at par with V_1T_3, V_1T_5, V_1T_6, and V_2T_3. However, V_1 T_9 i.e. Kufri Jyoti under control resulted in the lowest number of leaves per plant (36.60). Kufri Jyoti variety sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% resulted in 29.15% increment in the number of leaves over the growth in control. The varietal difference for number of leaves per plant may be due to the differences in height of the plant as number of leaves per plant increases with increase in plant height which can be seen from higher plant height in Kufri Jyoti as reported by Jatav *et al.* (2017).

Leaf Area (cm^2): Leaf area influences the interception and utilization of solar radiation of crop canopies and consequently dry matter accumulation and ultimately the tuber yield. The results of the leaf area per plant (cm^2) for different treatments, varieties, and interaction between treatments and varieties were found to be significantly significant ($p < 0.05$) and presented in Table 1. Among the different calcium nitrate and magnesium sulfate treatments, T_8 (Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%) lead to the largest leaf area (147.13 cm^2) which is significantly superior over all the treatments whereas, T_9 (control) resulted in smallest leaf area (122.95 cm^2). Among the varieties, V_2 (Kufri Chandramukhi) resulted in the largest leaf area (146.52 cm^2) in comparison to V_1 (Kufri Jyoti) (124.18 cm^2) that showed 17.99 % increase in the leaf area over latter (table1). Significant results were also observed for leaf area among the interaction between treatments and varieties. Interaction between different treatments and varieties showed that V_2T_8 i.e. Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% performs better and resulted in largest Leaf area (160.21 cm^2) and found to be significant over all other treatment combinations. However, V_1T_9 i.e. (Kufri Jyoti under control) resulted in the smallest leaf area (109.18 cm^2). Calcium helps in increase in the leaf area due to its role in cellular division and cell elongation. It also has a role in the process of photosynthesis and increases the accumulation of carbohydrates, thereby improving the vegetative growth of plants (Kafi *et al.* 2003). Similarly, magnesium helps in the formation of the chlorophyll molecule which further contributes pigments such as carotene, xanthophyll and is responsible for activation of a number of enzymes and coenzymes which further contribute to carbohydrate metabolism and consequently increases the vegetative growth as reported by Rehm (2008) and Alhatib (2007). The highest leaf area of variety Kufri Chandramukhi might be due to its inherent genetic makeup. The varietal difference for leaf area has also been reported by Raj *et al*. (2016).

Number of branches per plant: Results revealed that calcium nitrate and magnesium sulfate treatments had a non-significant effect on the number of branches per plant. However, numerically the highest value of number of branches per plant (5.00) was achieved under treatment T_1 i.e. Ca $(NO_3)_2$ @ 0.5% while the lowest value (4.28) was achieved under the T_2 i.e. $Ca(NO_3)_2$ @ 1 % treatment. The two varietal treatments exerted significant influence on the number of branches per plant. Kufri Jyoti obtained the maximum number of branches (5.38) as compared to the Kufri Chandramukhi variety (4.09) (table1). Data among the different interaction combinations showed non- significant results for the number of branches per plant. However, the highest value (5.65) for number of branches per plant in the interaction combination was achieved under V_1T_6 (Kufri Jyoti sprayed with $MgSO_4$ @ 2%) and the lowest value (3.36) was achieved by V_2T_3 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2%**)** interaction combination.The number of branches per plant was not affected by the application of calcium nitrate and magnesium sulfate treatments because the calcium has more impact on apical dominance, which inhibits the growth of lateral branches as reported by Ravichandran *et al.* (2015). The differences among the variety for number of branches per plant may be due to inherent and genetic characters of cultivars and better adaptability to prevailing environmental conditions. Present findings were in accordance with that of Preetham *et al.* (2018).

Fresh weight of shoots (g/plant): Significant results were recorded in different treatments and data reveals that fresh weight of shoots ranged from 130.13 g/plant to 189.72 g/plant. Among the different calcium nitrate and magnesium sulfate treatments, T_8 (Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%) lead to the maximum fresh weight of shoots (189.72 g/plant), which is significantly superior over all the treatments. The lowest 130.13g/plant fresh weight of shoots was recorded in T_9 (control). Among the varieties, V_1 (Kufri Jyoti) resulted in maximum fresh weight of shoots (160.77g/plant) in comparison to V_2 (KufriChandremukhi) (149.44 g/plant) that showed 7.58% increase in fresh weight of shoots over the latter. Significant results were also observed for the fresh weight of shoots among the interaction between calcium, magnesium treatments and varieties (table1). Interaction between different treatments and varieties showed that V_1T_8 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% performs better and resulted in highest fresh weight of shoots (194.53g/plant) and found to be significant over all other treatment combinations. However, $MgSO_4$ @ 1% i.e. T_5 in V_1 produced a significantly lower fresh weight of foliage (152.43 g/plant) followed by V_1 T_4 (Kufri Jyoti sprayed with $MgSO_4$ @ 0.5%), V_1T_1 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 0.5%) and V_2T_2 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 1%) and these interaction combinations are also significantly at par with each other. The lowest fresh weight of foliage (122.60 g/plant) was recorded in V_2 T_9 i.e. (Kufri Chandramukhi under control). The significant parity was also observed among the interaction combinations of V_2 T_6, V_2 T_5, V_2 T_3, and V_2 T_1. These findings are supported by Chowdhury (2017), who observed a significant increase in fresh weight of shoots upon applying different doses of calcium and magnesium in potato. The higher fresh weight of shoots might be due to increased membrane integrity and the role of calcium and magnesium in decreasing the losses due to various biotic and abiotic stress by Seifu (2017).

Dry weight of shoots (g/plant): Significant results were recorded in different treatments for dry weight of shoots. Among the different treatments, T_8 (Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%) lead to the maximum dry weight of shoots (32.90 g/plant). The significantly parity was observed in treatment T_1 i.e. Ca $(NO_3)_2$ @ 0.5%, T_4 i.e. $MgSO_4$ @ 0.5%, T_5 i.e. $MgSO_4$ @ 1% and T_6 i.e. $MgSO_4$ @ 2%. However,

Table 1 Effect of calcium and magnesium nutrition on vegetative growth of potato

Treatments	Plant Height (cm)		Number of leaves per plant		Leaf area (cm^2)		No. of branches per plant		Fresh weight of shoots (g/plant)		Dry weight of shoots (g/plant)	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
T_1 $Ca(NO_3)_2$ @ 0.5%	32.70	32.10	42.07	39.43	122.91	142.64	5.45	4.55	150.87	144.57	22.70	22.09
T_2 $Ca(NO_3)_2$ @ 1%	38.47	35.63	41.87	40.23	126.48	144.22	4.84	3.72	160.63	150.47	25.66	24.44
T_3 $Ca(NO_3)_2$ @ 2%	36.80	36.20	44.70	40.70	125.70	145.22	5.41	3.36	155.87	146.57	27.14	25.83
T_4 $MgSO_4$ @ 0.5%	30.67	30.30	41.37	37.90	119.90	142.19	5.25	4.41	149.47	138.67	21.89	20.74
T_5 $MgSO_4$ @ 1%	33.40	33.37	45.67	39.07	119.87	148.34	5.40	4.33	152.43	143.27	23.09	21.28
T_6 $MgSO_4$ @ 2%	33.53	34.67	44.90	39.53	124.58	140.28	5.65	3.59	154.57	143.33	24.18	22.20
T_7 $Ca(NO_3)_2$ 1%+ $MgSO_4$ @ 1%	47.67	39.63	47.27	42.43	134.91	158.89	5.63	4.09	190.93	170.63	32.72	29.21
T_8 $Ca(NO_3)_2$ 2%+$MgSO_4$ @ 2%	47.53	38.67	47.20	42.27	134.05	160.21	5.30	4.49	194.53	184.90	33.78	32.02
T_9 Control	27.27	29.93	36.60	37.87	109.18	136.72	5.49	4.27	137.67	122.60	17.23	13.09
Factors	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**
Varieties	1.088	0.166	1.893	0.289	4.82	0.736	0.93	0.142	1.647	0.251	1.699	0.259
Treatments	0.896	0.310	1.774	0.613	8.79	3.037	N/A	0.331	1.190	0.411	1.106	0.382
Varieties x Treatments	1.502	0.498	2.863	0.867	N/A	2.207	N/A	0.426	2.053	0.754	1.971	0.778

the minimum (15.16 g/plant) dry weight of shoots was observed in T_9 (control). Among the varieties, V_1 (Kufri Jyoti) resulted in maximum dry weight of shoots (25.38 g/plant) in comparison to V_2 (Kufri Chandremukhi) (23.43 g/plant) that showed a difference of 8.32% among both (table1). Significant results were also observed for dry weight of shoots among the interaction between treatments and varieties. Interaction between different treatments and varieties showed that V_1T_8 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% performs better and resulted in highest dry weight (33.78 g/plant) and found to be at par with V_1T_7 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 1% +$MgSO_4$ @ 1%) and V_2T_8 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%). Application of Ca $(NO_3)_2$ @ 1% and 2% to the variety Kufri Jyoti resulted in significantly similar production of the dry weight of shoots as achieved under variety Kufri Chandramukhi due to the application of Ca $(NO_3)_2$ @ 2% (V_2T_3). However, V_2T_9 i.e. (Kufri Chandremukhi under control) resulted in the lowest dry weight of shoots (13.09 g/plant). These findings are also in harmony with (Beltagy *et al.* 2002) and El-Zohiri and Asfour (2009) who revealed that Ca^{2+} fertilization increased the dry weight of the potato plant compared with control. Higher genetic potential promoted more photosynthesis and accumulation of dry matter and hence the drier weight of shoots per plant was recorded in variety Kufri Jyoti followed by Kufri Chandramukhi. Similar findings have been reported by Jatav *et al*. (2017).

Number of small tubers per plant: Among the different treatments, the lowest number of small tubers per plant were achieved by T_8 (1.55) i.e. application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%. However, the maximum number of small tubers per plant was found in T_9 (control) that was 3.43. Among the different varieties, the lowest number of small tubers per plant (2.31) was found in V_2 (Kufri Chandramukhi) whereas V_1 (Kufri Jyoti) produced a significantly highest number of small tubers per plant (2.37) (table2). Interaction between different treatments and varieties exhibited significantly significant results for number of small tubers per plant. Among the different interaction combination, the lowest number of small tubers per plant (1.45) was found in V_1T_8 i.e. by the spray of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% in variety Kufri Jyoti. The significant parity was observed in V_2T_7 (Spray of Ca $(NO_3)_2$ +$MgSO_4$ @1% each in variety Kufri Chandramukhi), V_1T_7 (Spray of Ca $(NO_3)_2$ @1% + $MgSO_4$ @1% in variety Kufri Jyoti) and V_1T_1 (Spray of Ca $(NO_3)_2$ @ 0.5% in variety Kufri Jyoti), V_2T_1 (Spray of Ca $(NO_3)_2$ @ 0.5% in variety Kufri Chandramukhi). However, the highest number of small tubers per plant was found in V_2T_9 (Kufri Chandramukhi under control) (3.56). The number of small tubers per plant was significantly reduced with the increase in the concentration of magnesium sulfate and calcium nitrate. These results were supported by the findings of Mani *et al.* (2014). According to Preetham *et al*. (2018) and Marwaha *et al*. (2007) the differences in number of small tubers between the varieties might be due to genetic variations and adaptability of the variety to prevailing climatic conditions of the experimental site.

Number of medium tubers per plant: the highest number of medium tubers per plant (5.04) was obtained under T_8 i.e. Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% which was significantly higher than all other treatments except (T_7) i.e. Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% (4.86), which was significantly similar to T_8. However, the lowest number of medium tubers per plant (3.55) was observed under the control T_9 (control). The significant parity was observed among the (T_1) i.e. Ca $(NO_3)_2$ @ 0.5%, (T_2) i.e. Ca $(NO_3)_2$ @ 1%, (T_4) i.e. $MgSO_4$ @ 0.5% and (T_5) i.e. $MgSO_4$ @ 1% treatment combinations. A progressive increase in the number of medium tubers per plant was reported with increasing concentrations of Ca $(NO_3)_2$ and $MgSO_4$. Combined application of $CaNO_3$ + $MgSO_4$ has a significantly better effect on the number of medium tubers per plant in comparison to alone application of $CaNO_3$ and $MgSO_4$. The number of medium tubers per plant was significantly influenced by the two varieties as Kufri Jyoti (V_1) achieved significantly higher number count (4.30) of the medium tubers per plant over the Kufri Chandramukhi (V_2) (4.09). The interaction effect of different calcium nitrate and magnesium sulfate treatments and varieties on number of medium tubers per plant at the time of harvesting revealed significant differences. Highest count (5.22) was obtained under V_1T_8 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%) and lowest (3.40) under V_1T_9 (Kufri Jyoti under control). Among the different interaction combinations, the significant parity was observed in V_2T_8 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%)

with V_1T_7 (Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1%) and V_2T_7 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1%). These findings get support from the work of Simmons and Kelling (1988) who reported an improvement in tuber grade by the application of calcium in the sandy soils. The variation in the number of medium tubers of potato genotypes may be due to genotypic and varietal factor. Similar results were reported by Marwaha *et al*. (2007), Khan *et al.* (2018) and Sadawarti *et al*. (2018) that different varieties had significant influence on number of medium tubers per plant.

Number of large tubers per plant: It is clear from the data that the best results in terms of number of large tubers per plant were given by application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% (3.54) concentration i.e. in treatment T_8 and was having significantly similarity with treatment T_7 (3.46) i.e. $CaNO_3$ @ 1% + $MgSO_4$ @ 1% concentration. The lowest number of large tubers per plant (2.82) was obtained under the control i.e. T_9 which was significantly lower than all other treatments (table 2). However, there was the non-significant difference among all the calcium nitrate treatments i.e. T_1, T_2, and T_3. The number of large tubers per plant was influenced significantly by varietal treatments. Kufri Jyoti (V_1) had given better results by producing a significantly higher number of large tubers per plant (3.39) over the Kufri Chandramukhi (V_2) variety that was recorded 3.14. The interaction effect of treatments and varieties showed that application of calcium nitrate and magnesium sulfate @ 2% each on variety Kufri Jyoti produces a higher number of large sized tubers (3.75) i.e. in V_1T_8. Among the other interaction combinations, the significant parity was observed in V_2T_8 (Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2%), V_2T_7 (Kufri Chandramukhi sprayed with $CaNO_3$ @ 1% + $MgSO_4$ @ 1%) and V_1T_7 (Kufri Jyoti sprayed with $CaNO_3$ @ 1% + $MgSO_4$ @ 1%). However, the lowest number of large tubers were found in V_2T_9 (Kufri Chandramukhi under control) (2.57). On the support to present findings, Russell (1975) found that the application of magnesium to potato crop resulted in a higher number of large tubers which ultimately enhance the total tuber yield mainly due to the role of magnesium in the transportation of phosphate. On the other side application of calcium to potato crop enhance the tuberization process as reported by Ozgen *et al.* (2003).

Yield of tubers

Yield of Small Tubers (g/plant): The calcium and magnesium treatments had a depressing effect on the yield of small tubers. The lowest and highest yield of small tubers was obtained under the T_8 treatment i.e. $CaNO_3$ @ 2% + $MgSO_4$ @ 2% (53.44 g/plant) and T_9 i.e. control (97.39 g/plant), respectively. All the treatments were significantly different from each other except T_1 & T_2 and T_3 & T_4 which were at par with one another. The yield of small tubers followed the decreasing trend when calcium and magnesium treatment concentrations were increased from 1 % to 2 %. The varieties had a significant effect on the yield of small tubers. Variety V_1 i.e. Kufri Jyoti (79.81 g/plant) had the significantly higher yield of small tubers over the V_2 i.e. Kufri Chandramukhi (70.44 g/plant). Among the interaction, the effect of different calcium and magnesium treatments and varieties exhibited significantly significantly results for the yield of small tubers. The lowest yield of small tubers was recorded in V_1T_8 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2.0% + $MgSO_4$ @ 2.0% (52.17 g/plant) and highest yield was found under V_2T_9 i.e. Kufri Chandramukhi control (94.71 g/plant). The significant parity was observed in V_2T_8 i.e. Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2.0% + $MgSO_4$ @ 2.0% (54.71 g/plant), V_1T_8 i.e. i.e. Kufri Jyoti sprayed with $Ca(NO_3)_2$ @ 2.0% + $MgSO_4$ @ 2.0%(52.17 g/plant) and V_2T_7 i.e. Kufri Chandramukhi sprayed with $Ca(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% (57.97 g/plant). According to Arsenault and Christie (2004), the variations between the varieties for small tuber weight were mainly due to reason that the plant height and number of branches may strongly influence the yield of small tubers. This was confirmed by the present findings where Kufri Jyoti had higher plant height and number of branches and hence produced the higher yield of small tubers.

Yield of medium tubers (g/plant): The different calcium and magnesium treatment combinations had exerted significant influence on the weight of the medium tubers. Yield of medium tubers was recorded maximum (173.99 g/plant) in T8 (Ca $(NO_3)_2$ @ 2.0% + $MgSO_4$ @ 2.0%) which was almost double of the T_9 (control) treatment which had the lowest (100.58 g/plant) yield of medium tubers. All the treatment combinations were significantly different from each other. The yield of medium tubers increased with an increase in the calcium nitrate and magnesium sulfate concentration. Foliar application of calcium nitrate and magnesium sulfate @ 2% was found to be superior over both 0.5% and 1.0% concentration. Data further reveals that the yield of medium tubers was also significantly affected by the two varieties. The yield of medium tubers was significantly higher in V_1 i.e. Kufri Jyoti (147.38 g/plant) as compared to the V_2 i.e. Kufri Chandramukhi (126.79 g/plant) variety. The interaction effects of treatments and varieties showed that application of calcium nitrate and magnesium sulfate @ 2 % each on variety Kufri Jyoti recorded maximum yield of medium tubers (187.75 g/plant) i.e. in interaction combination V_1T_8. However, the lowest yield of medium tubers was recorded in V_2T_9 i.e. Kufri Chandramukhi under control (98.12 g/plant). Among the other interaction combinations, the significant parity was observed in V_1T_3 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% (160.65 g/plant) and V_2T_8 Kufri Chandramukhi sprayed with Ca $(NO_3)_2$ @ 2.0% + $MgSO_4$ @ 2.0% (160.22 g/plant) (table 2). This might be due to the fact that the application of calcium nitrate and magnesium sulfate increases the tuber size, weight and number of medium size tubers per plant. Hence the yield of medium tubers was significantly increased with the increase in the concentration of calcium nitrate and magnesium sulfate. These results were supported by the findings of Simmons and kelling (1987).

Yield of large tubers (g/plant): It is evident from the data that different calcium nitrate and magnesium sulfate treatments had a significant and positive effect on the weight of large tubers per plant. The highest yield of large tubers (122.32 g/plant) was observed in T_8 i.e. Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% which was significantly at par with T_7 i.e. Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% (117.65 g/plant). Yield of large tubers was the lowest (80.54 g/plant) in T_9 (control). Ca $(NO_3)_2$@ 1% (T_2) significantly increased yield of large tubers over the Ca $(NO_3)_2$ @ 0.5% (T_1), but was at par with T_3 i.e. Ca $(NO_3)_2$@ 2%. Among the alone magnesium treatments, increase in large tubers weight was reported with increase in magnesium concentration, but $MgSO_4$ @ 0.5 (T_4) and 1.0 % (T_5) were significantly at par with one another. Effect of varieties on yield of large tubers had followed the same trend as that of medium and small tubers weight. Kufri Jyoti i.e. V_1 (115.60 g/plant) was significantly superior over the variety Kufri Chandramukhi i.e. V_2 (97.53 g/plant) in terms of the yield of large tubers. The interaction effect of different calcium and magnesium treatments and varieties on the yield of large tubers at the time of harvesting revealed significant differences. Highest weight (134.78 g/plant) was obtained under V_1T_8 i.e. Kufri Jyoti sprayed with $CaNO_3$+$MgSO_4$ @ 2% each and lowest yield (68.26 g/plant) under V_2T_9 (Kufri Chandramukhi under control). Among the other interaction combinations, the significant parity was observed in V_1T_1 i.e. Kufri Jyoti sprayed with $CaNO_3$ @ 0.5% with V_2T_7 i.e. Kufri Chandramukhi sprayed with $CaNO_3$ @ 1% + $MgSO_4$ @ 1% and V_2T_8 i.e. Kufri Chandramukhi sprayed with $CaNO_3$ @ 2% + $MgSO_4$ @ 2%. The increase in yield of large tubers might be due to the application of calcium and magnesium nutrition which influences the tuberization by altering the hormonal balance at the stolen tip as reported by Ozgen *et al.* (2003), Ozgen and Palta (2005).

Total tuber yield per plant (g): The highest total tuber yield per plant (321.46 g) was obtained by the foliar application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% i.e. in treatment T_8 and found to be significant over all the other treatments. The lowest total tuber yield per plant was obtained from the control i.e. T_9 (249.03 g). Foliar application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% (T_8) recorded 14.43% increase over (control) (T_9). Significant variations were observed among the results for different varieties. Kufri Jyoti (V_1) produced the highest total tuber yield per plant (310.21 g) and found significant over other variety (V_2). Minimum total tuber yield per plant (268.65 g) was produced in Kufri Chandramukhi (V_2). Kufri Jyoti resulted in 15.46% increase over Kufri Chandramukhi.Interaction between different treatments and varieties exhibited significantly non-significant results for total tuber yield per plant. However, maximum total tuber yield per plant (344.17 g) was recorded in T_8V_1 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% and minimum total tuber yield per plant (234.04 g) was recorded in T_9V_2 i.e. when Kufri Chandramukhi grows under control.These results are in conformity to the earlier findings of Hamdi *et al.* (2015) who demonstrated the effect of calcium on the total tuber yield per plant and found that plants treated with a high level of calcium had highest total tuber yield per plant while the least total tuber yield per plant was found in the control plots.

Table 2 Effect of calcium and magnesium nutrition on tuber yield of potato

Treatments	No. of Small Tubers Per Plant (< 25 g)		No. of medium tubers per plant (25 – 50 g)		No. of large tubers per plant (> 50g)		Yield of small tubers (g/plant)		Yield of medium tubers (g/plant)		Yield of large tubers (g/plant)		Total tuber yield per plant (g)		Tuber yield per hectare (q)		Marketable tuber yield per hectare (q/ha)	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
T_1 $Ca(NO_3)_2$ @ 0.5%	2.50	2.51	4.11	3.80	3.36	3.27	81.45	75.07	133.91	113.70	109.57	97.90	298.33	263.50	239.12	210.83	179.18	155.62
T_2 $Ca(NO_3)_2$ @ 1%	2.31	2.33	4.16	3.91	3.54	3.20	83.26	75.00	149.78	125.94	127.39	103.12	330.83	279.67	265.21	223.75	203.97	168.58
T_3 $Ca(NO_3)_2$ @ 2%	2.21	2.23	4.53	4.08	3.31	3.24	78.33	72.03	160.65	131.88	117.39	104.64	327.08	283.83	262.24	227.12	204.61	174.11
T_4 $MgSO_4$ @ 0.5%	2.70	2.38	3.75	4.03	3.55	3.15	84.71	67.32	117.61	113.84	111.59	89.42	271.30	243.42	231.01	199.18	168.65	149.62
T_5 $MgSO_4$ @ 1%	2.57	2.27	4.07	3.84	3.18	2.96	90.36	70.73	143.33	119.86	111.96	92.32	317.50	260.17	254.47	208.18	187.95	156.12
T_6 $MgSO_4$ @ 2%	2.36	2.09	4.36	3.96	3.22	3.16	81.67	66.45	150.94	125.65	111.52	100.36	299.88	258.50	253.37	215.30	193.24	166.37
T_7 $Ca(NO_3)_2$ 1%+ $MgSO_4$ @ 1%	1.88	1.77	5.09	4.64	3.50	3.42	66.23	57.97	179.35	151.88	123.41	111.88	338.75	295.96	271.51	236.81	222.79	194.15
T_8 $Ca(NO_3)_2$ 2%+$MgSO_4$ @ 2%	1.45	1.65	5.22	4.85	3.75	3.32	52.17	54.71	187.75	160.22	134.78	109.86	344.17	298.75	275.81	239.03	237.38	198.80
T_9 Control	3.30	3.56	3.40	3.69	3.06	2.57	100.07	94.71	103.04	98.12	92.83	68.26	264.01	234.04	217.81	192.18	144.15	122.47
Factors	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**	**C.D.**	**SE(m)**
Varieties	0.048	0.007	0.162	0.025	0.169	0.026	1.735	0.265	4.619	0.705	4.812	0.735	13.938	0.575	2.885	0.440	1.516	0.231
Treatments	0.116	0.04	0.177	0.061	0.089	0.031	3.278	1.133	4.634	1.601	4.991	1.725	9.818	2.987	6.950	2.402	5.642	1.95
Varieties x Treatments	0.168	0.022	0.277	0.074	0.171	0.078	4.81	0.794	7.368	2.115	7.884	2.204	N/A	1.724	N/A	1.321	8.059	0.694

Tuber yield per hectare (q/ha): Highest yield per hectare (257.42 q/ha) was obtained by the foliar application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% i.e. in T_8 and found to be significant over all the other treatments. The lowest yield was obtained from the control (T_9) (205 q/ha). Foliar application of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% recorded 25.60% increase over (control) (T_9). Significant variations were observed among the results of different varieties. Kufri Jyoti (V_1) produced the highest tuber yield per hectare (252.28 q/ha) which was significant over other variety (V_2) Kufri Chandramukhi (216.93 q/ha). Kufri Jyoti resulted in 16.29% increase over Kufri Chandramukhi.Interaction between different treatments and varieties exhibited significantly non-significant results for tuber yield per hectare. However, maximum tuber yield per hectare (275.81 q/ha) was recorded in T_8V_1 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% and minimum tuber yield per hectare (192.18 q/ha) were recorded in T_9V_2 i.e. when Kufri Chandramukhi was grown under control. It is apparent that calcium nitrate played an important role in increasing the total yield per hectare followed by magnesium sulfate. Combined application of $Ca(NO_3)_2$ and $MgSO_4$ has more effect on total tuber yield per hectare. On the support to present findings, Seifu (2017) concluded that with the application of calcium nitrate the average tuber yield of potato was increased up to 77% in the tested potato varieties.

Marketable tuber yield (q/ha): The marketable tuber yield had undergone significant influence with both the calcium and magnesium treatments. The lowest marketable tuber yield (133.31 q/ha) was obtained under the control (T_9) which was significantly lower than all other treatments. When calcium and magnesium were sprayed in combination i.e. T_7 and T_8, they had a more pronounced effect on the marketable tuber yield as compared to their alone application. Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% i.e. T_8 had the highest marketable tuber yield (218.09 q/ha) which was slightly higher than T_7 (208.47 q/ha) and was significantly different from all other treatments. There was no significant difference between Ca $(NO_3)_2$ @ 1% & 2% and Ca $(NO_3)_2$and $MgSO_4$both @ 0.5 % concentration. Both the varieties were significantly different from one another indicating a significant influence of the varietal treatments on the marketable tuber yield. Kufri Chandramukhi (V_2) had the marketable tuber yield of 165.09 q/ha which was significantly lower than Kufri Jyoti (V_1) having 193.55 q/ha marketable tuber yield. Interaction between calcium nitrate and magnesium sulfate treatments and varieties exhibited significantly significant results for the marketable tuber yield per hectare. Among the different interaction combinations, the highest marketable tuber yield was recorded in V_1T_8 i.e. Kufri Jyoti sprayed with Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% (237.38 q/ha) and least in V_2T_9 i.e. Kufri Chandramukhi under control (122.47 q/ha). The significant parity was observed in V_2T_7 (spray of Ca $(NO_3)_2$ @ 1% + $MgSO_4$ @ 1% in variety Kufri Chandramukhi) with V_2T_8 (spray of Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% in variety Kufri Chandramukhi). The higher marketable yield in variety Kufri Jyoti may be due to the maximum increase in growth attributes and higher yield of medium and large sized tubers. These results were in harmony with the findings of Raj *et al.* (2016).

Conclusion

From the results of the present study following conclusion have been drawn. Calcium nitrate and magnesium sulfate treatments had significantly affected the yield and growth parameters as well as late blight incidence in potato where Ca $(NO_3)_2$ @ 2% + $MgSO_4$ @ 2% proved to be the most effective treatment among all. it can be concluded that commercial cultivation of potato in the central region of Punjab can be successfully supplemented with application of Ca $(NO_3)_2$ + $MgSO_4$ and variety Kufri Jyoti.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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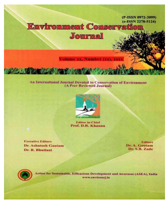

Studies on diversity of aquatic insects in Tamasi lake, Tahsil-Bhadravati, Dist- Chandrapur (M.S) India

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ABSTRACT

Aquatic insects are found abundantly and exhibits high diversity in fresh water aquatic ecosystems. They serve as food item for the vertebrate and invertebrate predators and thus play a significant role in aquatic ecosystem. Insects responded well to a wide range of environmental disturbances and thus often are employed as proxies for water quality. The present study was carried out at Tamasi Lake, situated in Bhadravati Taluka of Chandrapur district, Maharashtra which comes under Tribal area. The year round investigation was carried out to evaluate the diversity of aquatic insects for a period of one year from June 2022 to May 2023. The present investigation shows the presence of total 28 species of aquatic insects from 5 orders and 18 families. The rich and varied diversity of aquatic insects indicate the moderate environmental condition of freshwater ecosystem under study and functioning properly.

Introduction

An ecologically significant group of organisms in freshwater systems are aquatic insects. Knowledge of the ecology and biology of aquatic insects is essential for improving the understanding of the roles of insects in water quality and biodiversity, as well as community structure and ecosystem functioning. Lakes, ponds and reservoirs, are crucial for maintaining the biological balance of flora and fauna. Aquatic insects have a high capacity for tolerance to environmental changes (Merritt *et al.*, 2008). As a result, they can accurately predict any changes in water quality. Aquatic insects are a crucial component of many food cycles (Sharma *et al.*, 2010). Due to their contribution to energy and nutrient processing through food chains as well as their role in water purification, aquatic insects serve as a connecting link between aquatic and terrestrial ecosystems. Aquatic insects respond to certain changes in water conditions and act as indicators of aquatic ecology (Choudhary and Janak, 2015). Numerous viewpoints have been used to study the ecology of aquatic insects, including species diversity, life cycle and community structure, interactions between predator and prey, detritivory, grazing and implications for nutrient dynamics. The presence or absence of a species in an aquatic ecosystem reveals the extent of contamination (Wahizatul, *et al.*, 2011). Unlimited anthropogenic activities have a continuous effect on water quality. This affects the aquatic insects of lakes, which in turn disturbs the aquatic nutrient cycle. Aquatic insects are found to be very sensitive and moderately sensitive, and few are considered very tolerant. Ephemeroptera, Plecoptera and Trichoptera are excellent indicators because they are more sensitive to water pollution caused by natural disturbances and human anthropogenic activities (Cibik *et al.*, 2021). Species identification and their distribution patterns enriched the information regarding monitoring and conserving the ecosystem, Gulati (2012), Kumar (2014), Subramanian and Sivaramakrishan (2007).

Materials and Methods

Tamasi Lake is located in Bhadravati Taluka in the Chandrapur district and lies under the Tribal area. This lake consists of an earthen dam across a local nalla to the north side of Tamasi village. The cultural command area of the lake was 24.90 hectares. The

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irrigation potential of this lake is 24.90 Ha. Lake water is used for agricultural purposes and fishery activities. Currently, it functions as a backup reservoir for the purpose of providing water to nearby areas for agricultural purposes. Aquatic insects were collected using D-hand nets with a mesh size of 50 µm and dimensions of 30 × 30 cm. From each sampling site, an area of 50 m was selected for sample collection. Samples were collected by considering all possible insect habitats in the basin stream. The collected sample in the net was transferred into labeled plastic containers, preserved by adding 80% ethanol and taken to the laboratory for examination. The samples were placed in white trays for sorting and screening. The aquatic insects were manually collected from the trays. Large aquatic insects were sorted by the naked eye, whereas the sorting of the smaller insects was performed under a dissecting microscope. All the sorted samples were kept in properly labeled vials containing 80% ethanol. Aquatic insects were identified using the pertinent literature of Mishra (2007).

Results and Discussion

Aquatic insects were studied in the area of Tamasi Lake (Figs. 1 and 2). The aquatic insects studied are represented in Table 1. In the present investigation, a total of 28 species of aquatic insects from 5 orders and 18 families were recorded. Several biotic and abiotic factors are responsible for the abundance and diversity of insects. Temperature is the most important factor affecting the density of aquatic insects (Gupta & Paliwal, 2010). They are distributed in a variety of habitats with rich growth of macrophytes. Earlier studies revealed that more than 500 species of Odonata occur in India (Abhijna *et al*., 2013). Hemiptera, an order of true bugs, undergo gradual and imperfect metamorphosis. Both the adult and larval stages involve swimming or adhering to surfaces in water. Because of how they feed, hemipterans are significant. These methods are useful for reducing the mosquito population. Previous findings indicate that, compared to other insect groups, they are more resistant to environmental extremes (Ishas & Khan, 2013).

Figure 1: Satellite image of the lake under study

Figure 2: Overall view of Tamasi Lake, Teh: Bhadravati, Dist: Chandrapur

Table 1: Diversity of Aquatic Insects in Tamsi Lake during 2022-2023

Phylum	Class	Order	Family	Genera
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	*Choroterpes* sp.
			Caenidae	*Caenis* sp.
			Baetidae	*Cloeon bellum*
		Plecoptera	Perlidae	*Neoperla* sp.
		Trichoptera	Hydropsychidae	*Homoplectra* sp.
				Leptonema sp.
			Polycentropodidae	*Polycentropus* sp.
			Stenopsychidae	*Stenopysche* sp.
		Odonata	Coaenagrionidae	*Ceriagrion* sp.
				Pseudogrion sp.
			Libellulidae	*Libellula* sp.
				Brachythemis sp.
		Hemiptera	Belostomatidae	*Appasus* sp.
				Diplonychus sp.
			Gerridae	*Eurymetra* sp.
				Naboandelus sp.
			Corixidae	*Micronecta* sp.
				Sigara sp.
			Notonectidae	*Anisops* sp.
				Enithares sp.
			Naucordiae	*Naucoris* sp.
			Pleidae	*Macroris* sp.
				Plea pullula
			Nepidae	*Laccotrephes ater*
				Ranatra parvipes
			Hydrophilidae	*Hydrobius* sp.
			Dytiscidae	*Cybister* sp.
				Laccophilus sp.

Coleoptera, consisting of beetles and weevils, are conspicuous insects with brilliant metallic colors, patterns, and striking forms. The common names for both Cybister and Hydaticus include diving beetles.

Conclusion

The present study revealed the presence of 28 aquatic insect species with 05 major orders and 18 families, which indicates moderate environmental conditions. The order Hemiptera was the most diverse, representing 16 species, followed by Trichoptera and Odonata, each of which had a relatively low abundance of Plecoptera, with only one species. Some aquatic insects are sensitive to water pollution, whereas others are tolerant. The Knowledge of aquatic insects is essential for improving the understanding of the roles of aquatic insects in water quality, biodiversity, community structure and ecosystems. Therefore, ecological studies of aquatic insects are helpful for area of ecology for any decision-making.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Evaluation of different China aster (*Callistephus chinensis* L. Nees) genotypes in the Terai region of West Bengal

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ABSTRACT

The experiment was laid out in Randomized Completely Block Design with three replications. Sixteen genotypes namely, Arka Poornima, Arka Archana, Arka Aadya, Arka Kamini, Arka Shashank, Phule Ganesh White, Phule Ganesh Pink, Phule Ganesh Purple, Phule Ganesh Light pink, Pink Cushion, Arabhavi Aster Collection-1 (AAC-1), Namadhari Pink, Selected line (L-76), Selected line (L-179), Selected line (L-179/1) and Selected line (L-56) have been collected from IIHR, Hessaraghata Lake, Bengaluru, Karnataka for the trial.The different morphological, phenological as well as floral traits have been collected during the crop period which showed significant variation among the evaluated China aster genotypes. The maximum number of flowers per plant was recorded in 'Arka Aadya' (71.40) and 'Arka Shashank' (66.27) statistically at par with 'Arka Aadya' and the highest vase life as cut flower was noticed in Arka Shashank (11.67 days). Flower diameter was maximum in Phule Ganesh White (8.29 cm) which was at par with Arka Poornima (6.92 cm) and Phule Ganesh Purple (6.53 cm). Among the all genotypes, the maximum weight of ten fresh flowers were observed in Arka Poornima (54.17 g) which was statistically at par with Phule Ganesh White (53.61 g). These characters are considered to be very important with respect to commercial value of the variety for fulfil the consumers demand. The genotypes Arka Poornima, Phule Ganesh White, Arka Shashank, Arka Kamini and Arka Aadya may be recommended for commercial cultivation as loose flowers as well as cut flowers in the Terai region of West Bengal.

Introduction

China aster (*Callistephus chinensis* L. Nees) belongs to the largest family of flowering plants, 'Asteraceae'. The genus *Callistephus* is derived from two Greek words 'Kalistos' and 'Stephos' meaning 'most beautiful and 'a crown' referring to the flower head respectively. It was first named by Linnaeus as *Aster chinensis* but Nees changed this name to *Callistephus chinensis* (Janakiram, 2006). The plant is medium tall, 18 inches to 24 inches in height (Emsweller *et al.,* 1937). Strube (1965) described floral biology of China aster. The flower of China aster is head or capitulum which involves outer ray florets (pistillate) and central disc florets (hermaphrodite). According to him, its flower head consists of both pistillate ray florets and perfect disc florets. It is diploid (2n) having a chromosome number 2n=18 and is native to China. In India, China aster occupied approximately more than 5000 ha

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area. It is being grown in a few states of India like Maharastra, Karnataka, Tamil Nadu, West Bengal and Andhra Pradesh (Chowdhuri *et al.*, 2016). It is widely cultivated because of its wide spectrum of attractive colours and comparatively having longer vase life (Chaitra and Patil, 2007). Among the flowering annuals, China aster ranks third after Chrysanthemum and Marigold for popularity (Sheela, 2008). It is traditionally grown for its loose flowers as well as cut flowers. Due to long vase life as well as field life, these flowers are being used for various purposes like bouquets preparation, flower arrangements, bedding plants, edge, and herbaceous borders in gardens, flower shows and exhibitions. The dwarf genotypes of China aster are being used for edges and window boxes. The present-day Asters have been developed from a single form of wild species viz. *Callistephus chinensis.* The research works and recommendation of suitable genotypes for the Northern part of West Bengal is still now in the stage of infancy. The yield of flower and quality depend on varietal characters and greatly influenced by climatic factors. The climatic factors like photoperiod, temperature, relative humidity and also soil moisture influenced both vegetative and reproductive phases of the plant which ultimately leading to variation in the performance of genotypes. Hence, plants have to be exposed to proper climatic factors in order to get optimum and economic flower yields. The selection of genotypes for quality produces as well as to fulfil the market demand is an important factor however; the literatures and recommendation of suitable genotypes in this region are not available for commercial cultivation of China aster. It is essential to recommend a set of well performing genotypes of China aster for this region because the suitable agro climatic conditions are unique in nature for China aster cultivation under open field condition during winter session in the Terai region of West Bengal.

Material and Methods

The experiment on "Studies on performance of China aster (*Callistephus chinensis* (L. Nees) Genotypes in the Terai Region of West Bengal" was carried out at the Department of Floriculture, Medicinal and Aromatic Plants, Faculty of Horticulture, Uttar Banga Krishi Vishwavidyalaya, Pundibari, Cooch Behar, West Bengal, India during the year 2019-2020 and laid out in Randomized Completely Block Design with three replications. Sixteen Genotypes viz;Arka Poornima, Arka Archana, Arka Aadya, Arka Kamini, Arka Shashank, Phule Ganesh White, Phule Ganesh Pink, Phule Ganesh Purple, Phule Ganesh Light pink, Pink Cushion, Arabhavi Aster Collection-1 (AAC-1), Namadhari Pink, Selected line-76 (L-76), Selected line -179 (L-179), Selected line-179/1 (L-179/1) and Selected line-56 (L-56)were collected from Mahatma Phule Krishi Vidyapeeth, Rahuriand Indian Institute of Horticulture Research, Bengaluru and Selected lines were collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnatakafor the experiment.The seedlings of the genotypes have been planted at a spacing of 40cm X 40cm. The plot size was 2.00 m X 2.00 m and 25 plants were accumulated in a plot. The geographic position of the experimental site is 26.40˚N latitude and 89.38˚E longitude. The site lies in the sub-Himalayan plains with an altitude of 44m above mean sea level and falls under the Terai Agro-climatic Zone of West Bengal. At the time of land preparation 25 tonnes of well decomposed FYM per hectare and 90: 60: 60 kg NPK per hectare were applied and top dressing @ 90 kg/ha of nitrogen was applied after 40 days of transplanting (Rao *et al.*, 2012). All the intercultural operations and plant protection measures were taken whenever required. The observations recorded on various growth and flowering parameters were subjected to analysis of variance (ANOVA) using randomized block design (Gomez and Gomez 1984). and OPSTAT online statistical analysis software. The details of Pedigree and /or collection Centre of evaluated genotypes are furnished in table 1.

Results and Discussion

Significant variation in vegetative attributes like plant height (cm), plant spread (cm), leaf area at flowering stage (sq.cm) and number of branches per plant at flowering stage were recorded among the genotypes of China aster during this investigation which presented in Table 2. At the stage of one month (30 days) after transplanting, the genotype, Arka Poornima recorded maximum plant height (17.41 cm) whereas, the lowest plant height was recorded in Arka Aadya with an ordinary height of 4.23 cm.

Table 1: Details of evaluated genotypes of of China aster in the Terai region of West Bengal

S. No.	Name of the genotypes	Collection centre and brief description
1.	Arka Poornima.	AST -29 X AST-3, collected from Indian Institute of Horticulture Research, Bengaluru
2.	ArkaAadya	Selectin from population of line no. 173, collected from Indian Institute of Horticulture Research, Bengaluru
3.	Arka Archana	Selected from selfed population of line no. 15, collected from Indian Institute of Horticulture Research, Bengaluru
4.	Arka Shashank	Local Pink & AST 2 collected from Indian Institute of Horticulture Research, Bengaluru
5.	Arka Kamini	AST-6 X AST-36, collected from Indian Institute of Horticulture Research, Bengaluru
6.	Phule Ganesh Purple	Institutional released variety (AICRP ON Flori. Ganeshkhind, Pune/ M.P.K.V, Rahuri), collected from Mahatma Phule Krishi Vidyapeeth, Rahuri
7.	Phule Ganesh white	Institutional released variety (AICRP ON Flori. Ganeshkhind, Pune/ M.P.K.V, Rahuri), collected from Mahatma Phule Krishi Vidyapeeth, Rahuri
8.	Local Pink	Locally collected genotype.
9.	Phule Ganesh Light Pink	Institutional released variety (AICRP ON Flori. Ganeshkhind, Pune/ M.P.K.V, Rahuri),collected from Mahatma Phule Krishi Vidyapeeth, Rahuri
10.	Phule Ganesh Pink	Institutional released variety (AICRP ON Flori. Ganeshkhind, Pune/ M.P.K.V, Rahuri), collected from Mahatma Phule Krishi Vidyapeeth, Rahuri
11.	Selected line-56	AAC-1 X ArkaPoornima, collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka
12.	Selected line-76	Arka Kamini X Phule Ganesh Purple, collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka
13.	Selected line-179	AAC-1 X Arka Poornima, collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka
14.	Selected line-179-1	AAC-1 X ArkaPoornima, collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka
15.	AAC-1	Hybridization (Arabhavi Aster collection 1), OP Seedling selection from germplasm, collected from Kittur Rani Channamma College of Horticulture, Arabhavi, Karnataka
16.	Namdhari Pink	Collected from Namdhari Seed company, Bengaluru

The final plant height was also measured at flowering stage and the maximum plant height (89.45 cm) was recorded in genotype Phule Ganesh Purple which was significantly taller than L-179 (83.89 cm) and Phule Ganesh Pink (81.63 cm). Minimum plant height was noticed in genotype Arka Archana (33.02 cm) at flowering stage. Plant spread, at the stage of one month after transplanting, in East – West direction was maximum in genotype Phule Ganesh purple (20.93 cm) which was followed by Phule Ganesh Pink (19.25 cm), Phule Ganesh Light Pink (19.00 cm) and L-179/1 (18.67 cm). The plant spread in North – South Direction after 30 days of transplanting was minimum in genotype Arka Kamini (10.41 cm) which was at par with Arka Poornima (11.01 cm) and Arka Shashank (11.22 cm). The maximum plant Spread at the time of flowering, in East – West direction was recorded in AAC-1 (49.57 cm) which was at par with Phule Ganesh Purple (40.33 cm) and L-179 (39.83 cm), whereas the lowest was recorded in Arka Poornima18.67 cm) followed by Arka Kamini (27.73 cm) and Arka Shashank (32.11 cm). The highest plant spread in North – South direction was recorded in cv. AAC-1 (49.23 cm) it was at par with L-76 (40.17 cm) and Phule Ganesh White (40.10 cm), whereas lowest was recorded in Arka Poornima (17.82 cm).The genotype Phule Ganesh Purple (23.07) produced a greater number of branches per plant followed by AAC-1 (22.67) and L-59 (20.28) but the least branches were noticed in genotype Arka Poornima (6.67) at flowering stage.The maximum leaf area (11.70 sq.cm) was recorded in genotype Phule Ganesh pink and the minimum were recorded in genotypes Arka Kamini and ArkaAadya (3.63 sq.cm and 5.40 sq.cm respectively).

Table no. 2. Performance of China aster genotypes for vegetative characters in the Terai Region of West Bengal

Genotypes	Plant height (cm)		Plant spread (cm)				Leaf area at flowering stage (sq.cm)	Number of branches at flowering stage
	30 DAT	At flowering stage	30 DAT		At flowering stage			
			E-W	N-S	E-W	N-S		
Arka Poornima	17.41	37.65	11.34	11.01	18.67	17.82	10.27	6.67
Arka Archana	8.40	33.02	12.96	12.97	37.30	35.24	7.00	8.87
ArkaAadya	4.23	66.48	14.68	15.37	39.63	39.21	5.40	18.60
Arka Kamini	6.99	37.71	10.95	10.41	27.73	26.47	3.63	13.67
Arka Shashank	11.40	56.51	12.66	11.22	32.11	29.57	7.57	13.87
Phule Ganesh White	12.89	65.93	14.81	13.43	36.93	40.10	6.73	9.60
Phule Ganesh Pink	11.27	81.63	19.25	19.40	33.70	29.92	11.70	14.80
Phule Ganesh Purple	9.93	89.45	20.93	19.13	40.33	36.47	10.63	23.07
Phule Ganesh Light Pink	8.04	80.25	19.00	20.13	33.30	29.87	7.40	19.27
Pink Cushion	12.51	56.76	14.35	14.57	35.04	31.39	8.47	9.53
AAC-1	7.01	69.95	13.67	15.33	49.57	49.23	10.27	22.67
Namdhari Pink	8.09	63.57	12.72	14.09	34.27	33.23	10.17	18.47
Selected line (L-76)	9.73	73.37	17.60	18.00	36.37	40.17	9.93	19.33
Selected line (L-179)	11.56	83.89	18.50	16.67	39.83	36.40	9.67	18.40
Selected line (L-179/1)	12.85	79.58	18.67	17.90	39.50	39.17	10.13	18.24
Selected line (L-56)	15.57	75.13	16.53	17.97	36.40	39.17	9.73	20.28
Mean	10.49	65.68	15.54	15.47	35.67	34.59	8.67	15.96
S. Em (±)	0.60	2.36	0.67	0.75	1.99	1.90	0.16	1.11
CD at 5%	1.74	6.81	1.94	2.16	5.75	5.48	0.47	3.20

***DAT-** Days after transplanting

Table 3 revealed that the genotype Arka Poornima recorded the least number of days to first bud initiation (39.27 days), whereas genotype AAC-1 recorded the highest number of days for first bud initiation (75.67 days). Thegenotype 'Arka Poornima' took minimum number of days (58.27 days) to first flower opening after planting which wasstatistically difference with genotype 'Pink Cushion' (61.47 days) and cv. 'Arka Shashank' (63.13 days). Whereas, genotype 'AAC-1' was late to reach first flower opening (97.67 days). The genotype Arka Poornima took minimum number of days (70.07 days) to first flower full blooming and significantly differed with genotype namely Arka Shashank (73.67 days) and Pink Cushion (74.07 days) whereas the genotype AAC-1 took maximum number of days (108.27 days) to first flower full blooming followed by genotype Phule Ganesh Purple (100.87 days).The genotype AAC-1 took maximum number of days (120.97 days) to first flower wilting from transplanting followed by genotypes Phule Ganesh Purple (115.17 days) and Phule Ganesh Pink (109.37 days). The genotype Arka Poornima (83.07 days) took minimum number of days to first flower wilting. The genotype Arka Shashank (40.00 days) produced flower for long period. Minimum duration of flowering was observed in genotype AAC-1 (26.67 days) and L-76 (30.00 days).

Table no. 3. Performance of China aster genotypes for flowering characters in the Terai Region of West Bengal

Genotypes	Total nos. of flowers per plant	Total nos. of flowers per bed	Flower diameter (cm)	Stalk length (cm)	Wt. of 10 fresh flowers (g)	Wt. of 10 dried flowers (g)	Vase life (days)
Arka Poornima	23.87	585.67	6.92	17.09	54.17	9.57	8.33
Arka Archana	45.13	1091.67	6.44	13.87	38.87	8.45	9.67
ArkaAadya	71.40	1707.33	5.57	18.00	29.41	5.71	8.67
Arka Kamini	43.53	1025.00	6.36	14.69	32.03	8.72	7.67
Arka Shashank	66.27	1570.67	6.20	21.53	42.60	8.80	11.67
Phule Ganesh White	48.67	1175.33	8.29	25.19	53.61	9.38	9.67
Phule Ganesh Pink	42.93	1043.67	6.35	15.21	42.15	9.11	9.00
Phule Ganesh Purple	42.33	1021.67	6.53	15.07	46.47	9.29	9.00
Phule Ganesh Light pink	50.80	1240.67	5.66	15.81	41.22	8.82	9.00
Pink Cushion	46.93	1142.33	5.95	21.92	24.88	5.56	7.67
AAC-1	41.20	1010.00	5.98	25.91	45.30	8.88	7.33
Namdhari Pink	51.47	1266.00	5.99	20.99	24.24	6.68	8.00
Selected line (L-76)	48.27	1170.33	5.05	22.53	36.38	4.81	6.67
Selected line (L-179)	66.13	1517.33	5.43	22.43	38.06	5.12	8.00
Selected line (L-179/1)	60.07	1469.33	5.24	20.46	36.47	5.19	8.00
Selected line (L-56)	50.73	1116.67	4.24	23.71	39.56	5.08	7.00
Mean	49.98	1197.10	6.01	19.65	39.09	7.45	8.46
S. Em (±)	2.37	68.15	0.19	1.31	1.61	0.64	0.35
CD at 5%	6.84	196.84	0.56	3.78	4.66	1.85	1.02

Performance of China aster genotypes for flowering characters in the Terai Region of West Bengal represented in Table 4. The maximum number of flowers per plant were recorded in genotype ‘ArkaAadya’ (71.40) which was statistically at par with genotypeArka Shashank and genotype L-179.On the other hand, the minimum number of flowers per plant was recorded in genotypeArka Poornima (23.87). The genotypeArkaAadya was significantly better than genotypeArka Shashank (66.27), L-179 (66.13) and L-179/1 (60.70). Maximum number of flowers per bed were recorded in genotypes ‘ArkaAadya’ (1707.33) and ‘Arka Shashank’ (1570.67) which were statistically at par with the best. While least flowers per bed were noticed in genotype ‘Arka Poornima’ (585.67). The genotype ‘AAC-1’, ‘Phule Ganesh Purple’, ‘Arka Kamini’, ‘Phule Ganesh Pink’, and ‘Arka Archana’ (1010.00, 1021.67, 1025.00, 1043.67, and 1091.67 respectively.) were also better as compare to the best cv. Arka Aadya in regards to total number of flowers per plot. Flower diameter was maximum in genotypes Phule Ganesh White (8.29 cm) which was statistically at par with genotypesArka Poornima (6.92 cm) and Phule Ganesh Purple (6.53 cm). The minimum size of flower was observed in L-56 (4.24 cm) which showed significantly differed with the large size flower. The longest flower stalk was recorded in genotype AAC-1 (25.91 cm) and it was statistically at par with genotype Phule Ganesh White (25.19 cm), genotype L-76 (22.53 cm) and genotype L-179 (20.43 cm). Whereas shortest stalk length was recorded in cv. Arka Archana (13.87 cm). Among all the genotypes, the maximum weight of ten fresh flowers was observed in genotype Arka Poornima (54.17 g) which was statistically at par with genotype Phule Ganesh White (53.61 g). While the minimum weight of ten fresh flowers were recorded in genotype Namdhari Pink (24.24 g). The maximum dry weight of ten flowers recorded in genotype Arka Poornima (9.57 g) and minimum in genotype L-76 (4.81 g). The highest vase life was noticed in genotype Arka Shashank (11.67 days). Whereas the lowest was noticed in genotype L-76 (6.67 days).

Table 4. Performance of China aster genotypes for phenological characters in the Terai Region West Bengal

Genotypes	First Flower Bud Initiation (Days)	First Flower Opening (Days)	First Flower Full Opening (Days)	First Flower Wilting (Days)	Duration of Flowering (Days)
Arka Poornima	39.27	58.27	70.07	83.07	33.67
Arka Archana	46.93	66.13	76.53	91.87	36.33
ArkaAadya	61.00	73.53	82.73	96.33	32.33
Arka Kamini	66.60	75.13	87.80	101.23	32.00
Arka Shashank	40.20	63.13	73.67	90.73	40.00
Phule Ganesh White	43.53	67.80	77.53	92.63	31.67
Phule Ganesh Pink	72.20	84.60	95.00	109.37	30.67
Phule Ganesh Purple	71.87	90.80	100.87	115.17	30.33
Phule Ganesh Light pink	64.87	78.80	89.93	104.30	30.33
Pink Cushion	42.27	61.47	74.07	87.10	32.33
AAC-1	75.67	97.67	108.27	120.97	26.67
Namdhari Pink	46.27	65.73	76.53	90.50	30.67
Selected line (L-76)	53.53	70.67	80.47	93.33	30.00
Selected line (L-179)	56.67	76.53	85.27	98.43	30.67
Selected line (L-179/1)	54.20	74.80	84.87	98.23	30.67
Selected line (L-56)	56.53	74.40	84.93	97.40	31.00
Mean	***55.73***	***73.72***	***84.28***	***98.17***	***31.83***
S. Em (±)	***0.87***	***0.89***	***0.94***	***1.09***	***0.83***
CD at 5%	***2.51***	***2.57***	***2.71***	***3.16***	***2.38***

The plant height of the evaluated genotypes showed differences significantly at initial stages (30 DAT), however the 'Phule Ganesh series' showed the maximum plant height at flowering stage. The genotype 'Phule Ganesh Purple' attained maximum plant height at the stage of peak growth period. Among the genotypes, plant spread varied significantly. The maximum plant spread was noticed in genotypes 'AAC-1', 'Phule Ganesh Purple', and 'Phule Ganesh White' at peak flowering stage. From the experiment, it may be recommended that the genotypes Phule Ganesh series namely Phule Ganesh Pink, Phule Ganesh Purple, Phule Ganesh Light Pink, AAC-1, L-76, L-179, are suitable for commercial cultivation in Terai region of West Bengal both as cut flower and loose flower. The genotypes like Arka Poornima, Arka Archana and Arka Kamini recommended for pot culture and garden display as well as loose flower production. Similar findings were also reported earlier in China aster by Chowdhury*et al.,* (2016), Rai and Chaudhary (2016), Dilta *et al*., (2007), Munikrishnappa *et al*., (2013) and in Chrysanthemum Singh *et al.,* (2017) and Kulkarni (2003). The genotype 'Arka Poornima' comparatively took minimum number of days for first flower bud initiation, and the least number of days to first flower opening and first flower full blooming were also noticed. Maximum flower diameter was recorded in genotype 'Phule Ganesh White' and also recorded maximum flower stalk length (25.19 cm) next to the genotype 'AAC-1' (25.91 cm). The genotype 'Arka Shashank' recorded maximum duration of flowering (40.00 days), and also recorded maximum days of vase life as cut flower in vase. The genotypes also showed wide variation in their productivity i.e. number of flowers per plant. The maximum number of flowers per plant were recorded in genotype 'Arka Aadya' (71.40) and 'Arka Shashank' (66.27). The quality attributes of flowers are very important to fulfilling the consumer demand. Similar results were reported earlier by Kumar *et al*., (2016), Gaikwad *et al.,* (2002) and Martolia and Rao (2018) in China aster. The genotypes 'Arka Poornima', 'Phule Ganesh White', 'Arka Shashank', and 'ArkaAadya' may be recommended for commercial cultivation as loose flowers as well as cut flowers in the Terai region of West Bengal. The genotype 'Arka Poornima' took minimum number of days to first flower opening which was followed by genotype 'Pink Cushion' and genotype'Arka Shashank'. On the other hand, genotype AAC-1 took maximum number of days for its flower opening. The difference in flower bud initiation and flower opening by genetic traits and may be influence of solar radiation and temperature. Earlier, these kinds of results also reported by Rai and Chaudhary (2016), Chowdhuri *et al.,* (2016), Dilta *et al.,* (2007), Zosiamliana *et al*., (2011), Aditya *et al.,* (2019), Martolia and Rao (2018) in China aster. Negi *et al.,* (1988) and Dilta*et al.,* (2005) in chrysanthemum also reported the similar results. With concerned to days taken for first flower full blooming, the genotypes Arka Poornima, Arka Shashank and Pink Cushion took minimum number of days for first flower full blooming. Whereas the genotypeAAC-1 and Phule Ganesh Purple reached in late to full blooming. Similar genotypeon varietal trend also observed by Chowdhuri*et al.,* (2016) in China aster. With respect to stalk length, the significant differences were observed among genotypes in China aster. The maximum stalk length was noticed in genotype AAC-1 which was at par with genotypes Phule Ganesh White, L-76, L-179, L179/1 whereas minimum stalk length was noticed in genotype Arka Archana. The differences in stalk length among the genotypes might be attributed to the inherent genetic character associated with the genotypes. Variation in stalk length was also noticed in different genotypes of China aster by Zosiamliana *et al*., (2011) and Rai and Chaudhary (2016). Kumar and Yadav (2005) and Ambad *et al.,* (2001) also reported the genotypes of gerbera as per their quality attributes due to their inherent genetic differences. More number of flowers per plant was recorded in the genotype Arka Aadya, while the genotype Arka Poornima produced the least number of flowers per plant. Significantly maximum number of flowers per bed was produced by genotype Arka Aadya and least per bed was produced by cv. Arka Poornima. The flowers produced per plant may be directly related with the production of maximum number of leaves, more plant spread, more number of branches per plant, due to synthesis of maximum photosynthates which resulted in production of good number of flower buds on the branches. The similar results were reported in China aster by Munikrishnappa *et al*., (2013), Rai and Chaudhary (2016), Chowdhuri *et al.,* (2016), Savitha *et al*., (2016), Kumar *et al*., (2016) and Dilta *et al*., (2007). Negi *et al.,* (1988) and Singh *et al.,* (2004) also reported similar evidence in Chrysanthemum and Marigold respectively.The results of having significant and positive correlations between plant height and other characters *viz*. plant spread in East-West, plant spread in North-South, leaf area, number of branches, days to first flower full opening, days to first flower wilting, and total number of flowers per plant might indicate the strong bearings of different physiological parameters like photosynthetic efficiency, translocation efficiency and reproductive development on plant growth. These physiological parameters are actually governed by genotypes and substantially influenced by environmental factors. Similar results were recorded by Poornima et al., (2006); Harishkumar *et al.,* (2018) and Tirakannanavar *et al.,* (2015) in China aster. The results of positive and highly significant correlation of total number of flowers per plant with plant height, plant spread in East-West, plant spread in North-South, number of branches andseed yield per plant were in agreement with earlier results reported in china aster (Harishkumar *et al.,* 2018; Tirakannanavar *et al.,* 2015; Naikwad *et al.,* 2018). Similar results were also observed by Vikas *et al.,* (2011) in dahlia.

Conclusion

It may, therefore, be assumed from the findings that the genotypes which performed better in respect of quality traits may be selected for commercial production as well as further crop improvement program. The flower size (Arka Poornima, Arka Archana, Arka Kamini, Phule Ganesh White and Phule Ganesh Purple), stalk length (Phule Ganesh Pink, AAC-1 and Selected line, L-56), production of maximum number of flowers per plant (Arka Aadya, Arka Shashank and Selected line (L-179) and remaining fresh for long time after harvesting (Arka Archana, Arka Shashank and Phule Ganesh White) are the most wanted criteria for selecting the genotypes which may be fulfilled the demand of the consumers. Considering the quality attributes have been evaluated in this study, the genotypes namely, 'Arka Poornima', 'Phule Ganesh White', 'Arka Shashank', Arka Kamini, and 'Arka Aadya' may be selected for commercial cultivation for loose flowers production as well as for cut flowers production in the Terai region of West Bengal.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Water quality parameters and population of aquatic insect larvae in Pardi Lake, Gadchiroli District (M.S.) of India

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ABSTRACT

The present research deals with the study on some physicochemical parameters and the population of aquatic insect and insect larvae of Pardi lake, Gadchiroli which was carried out from February 2016 to January 2017. Total 10 genera of aquatic insect larvae recorded during the present piece of investigation, among which Order Diptera is represented by 07 genera and Coleoptera by 03 genera. The Dipteran species are found to be dominant in the lake. The high density of pollution indicator species like *Chironomus*, *Eristalis* and *Trichoptera larvae* indicates the polluted nature of the lake. Thus, keeping in view the importance of the study, the necessary steps should be taken for the conservation and maintenance of lake.

Introduction

India is very rich in water resources and is the second largest country in the world. Water is an elixir, blue gold, and abundant and the most precious natural resource on Earth. It is a medium of life. Water has the capacity to dissolve an extremely wide variety of substances. It is very useful to organisms and humans. Aquatic insect larvae are important aquatic fauna that contribute to the trophic structure of ecosystems and serve as a major component of the aquatic food chain. In freshwater ecosystems, aquatic macroinvertebrates are key inhabitants. Among the macroinvertebrates, the most abundant macroinvertebrates are insects (Macadam & Stockan, 2015). Many aquatic insects have both aquatic (larval and adult) and terrestrial (adult) life stages. The impact of aquatic insects is not limited to the aquatic environment alone but also affects stretches into the terrestrial riparian environment. This study aimed to determine the diversity of lake insect communities and lake water quality and to investigate the relationships between insect communities and water quality parameters.

Materials and Methods

In India, the seasonal conditions of pond life in Punjab, appears to be the first hydrobiological study. Several workers, such as Macadam and Stockan (2015**),** Fatalmoudou *et al.* (2018), and Kleber and Rhainer (2019), made noteworthy contributions to the field.

Study area (Pardi Lake, Gadchiroli):

Gadchiroli, a district headquarters of the Nagpur division of state Maharashtra, is situated at 20.09' 45"N 790' 55' 39"E in the northeastern region. The lake investigated was Pardi Lake, which has lovely sites. The lake is primarily used by inhabitants for domestic and agricultural purposes. Pardi Lake has a surface area of 3.21 hectors (9 acres) and an average depth of 10 feet and fills up after a heavy downpour in Pardi town.

Sampling sites

The sampling sites were marked by means of a weighted plastic float. Water samples were collected at monthly intervals in clean plastic containers using the standard method of collection and were subsequently transported to the laboratory for further estimations (APHA, 2005).

Sampling of aquatic insects and larvae

Aquatic insects were collected during the daytime, and the collected samples were subsequently

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transferred to individual jars containing water obtained from their habitat. Subsequently, the plants were placed in glass vials containing 90% ethyl alcohol. The vials were labeled for date and location. A stereo-typed microscope and dissecting microscope were used for observation and identification of the samples. The specimens were well preserved in the laboratory.

The results were recorded on a data sheet based on the order, family and genus. Aquatic insects were identified up to the genus level using the taxonomic keys of Yule and Yong (2004), Verma (2016), Verma (2017a), Vidotto-Magnoni and Carvalho (2009), Williams and Williams (2017).

Water sample analysis

The standard procedures of APHA (2005) were adopted for the analysis of water samples. The physico-chemical parameters, such as water temperature, pH, dissolved oxygen, free CO2, total alkalinity, phosphate (PO4)3- and nitrate (NO3-), were analyzed. The water temperature was determined by using a mercury thermometer. The pH of the water was determined using a pH meter (HANNA, Model no. -H19). In situ parameters, temperature (^{0}C), pH, and dissolved oxygen (DO) concentration (mg/l), were tested. DO, free CO_2, total alkalinity, nitrate and phosphate parameters were analyzed using the methods of APHA, AWWA and WPCF (2005). Aquatic insect larvae were randomly collected using a Surber net 0.3 m × 0.3 m in size at different sites in the lake. The samples were transferred to a plastic Zipper bag with 75% ethanol for preservation and returned to the laboratory for identification. The aquatic insect larvae were sorted and identified based on their morphology.

Results and Discussion

Pardi Lake Gadchiroli (M.S.) is a shallow mesotrophic lake that supports the larval population of aquatic insects. The morphometry of the lake is given in Table 1, and the diversity of the aquatic insect larvae population in different seasons is given in Table 2. The findings of the present investigation are described as follows:

Water temperature: Water temperature strongly fluctuates from a minimum of 16.10°C to a maximum of 23°C, and high temperatures from March onward initiate rapid decomposition of the organic matter in the substrate. Consequently, the mineral content in the lake water increased. The increase in water temperature was probably due to low flow conditions and heavy sunshine. These observations are similar to those of (Prommi & Payakka, 2015).

Table 1: Morphometry of the lake

Features	Morphometry
Shape	Slightly rectangular in shape.
Length	308 Meter
Width	158 Meter
Minimum Depth	10 Feet
Maximum Depth	15 Feet
Mean Depth	12.5 Feet
Surface Area	3.21 Hector (9 acre)
Water Volume	1, 44,000 meter^3
Type and Source of Water.	Perennial, Rain water is source,
Management status	Moderately managed, concrete dyke, fish culture practices
Political Status	MaMaTalav

pH: In the present study, pH values ranging from 7.7-8.4 were most suitable for fish production. The water at approximately pH 7 is called neutral. During daylight, aquatic plants usually remove CO_2 from water quickly, and the pH increases. At night, CO_2 accumulates, and the pH decreases. The magnitude of the daily fluctuation in pH depends on the buffering effect. pH is the most stable parameter, with small differences, and is also the most stable parameter every 3 months, with no drastic changes. These results are in agreement with those of Parveen (2010).

Dissolved oxygen (DO): During winter months, dissolved oxygen is plentiful when submerged macrophytes are luxuriant, as is dissolved oxygen during monsoon months when there is rich microplanktonic vegetation and excess oxygen is added from intensive rainfall. The minimum value of 11.09 mg/L was observed in December, and the maximum value of 27.0 mg/L was observed in February. The oxygen produced during this period often exceeds the amount of oxygen consumed by the organism. This finding conforms with the findings of Vafaei *et al.* (2007) and Turkmen and Kazanci (2013).

Free carbon dioxide (FCO_2): was detected mainly from the polluted region during the winter and monsoon months. The minimum value of 2.00 mg/L was recorded in June, and the maximum value of 14 mg/L was recorded in October. CO2, like other gases, readily exchanges with the atmosphere and is supersaturated with respect to the atmosphere. The results of this supportive study are from Tripathi *et al*. (2016), Verma (2017b and c), and Suhaila and CheSalmah (2017), Verma and Prakash (2018).

Table 2: Diversity of aquatic insect larvae in different seasons at Pardi Lake, Gadchiroli (M.S.)

Order	S N	Aquatic insect larvae population	Winter			Summer			Monsoon		
			Site A	Site B	Site D	Site A	Site B	Site D	Site A	Site B	Site D
Diptera	1	*Anopheles larvae,*	++	+	+	+++	+	-	+++	++	+
	2	*Culex larvae,*	++	++	+	+++	+	-	+++	++	+
	3	*Eristalis larvae,*	++	++	+	+++	++	+	+++	+	+
	4	*Trichoptera larvae,*	++	++	+	++	++	+	+++	+	-
	5	*Chironomus larvae,*	++	++	+	++	++	+	+++	++	+
	6	*Psychoda larvae,*	+	-	+	+	-	-	+	+	-
	7	*Dixa larvae*	+	-	+	+	+	+	++	+	+
Coleoptera	1	*Hydroporus larvae,*	+	-	-	+	+	-	+	+	+
	2	*Helichus larvae*	-	+	-	-	+	+	+	-	-
	3	*Cybister larvae*	++	+	+	+	+	++	+	+	+
	[Site-(A) Village site, Site (B) Dhobi ghat, Site (C)- Agriculture site] +++ Abundance, ++ Moderate, + Rare, - totally absent										

Table 3: Mean values of water quality parameters of the lake

Month	PHYSICO-CHEMICAL PARAMETERS						
	WT (^{0}C)	pH	DO (mg/l)	FCO_2 (mg/l)	TA (mg/l)	Phosphate (mg/l)	Nitrate (mg/l)
Feb-16	18.5	8.0	**27.0**	11.9	195	0.077	0.41
March-16	20.1	7.9	25.6	12.5	187	0.076	0.40
April-16	19.5	7.8	24.9	10.4	225	0.069	**0.42**
May-16	22.0	7.8	26.8	5.8	**260**	**0.080**	0.38
June-16	**23.0**	**7.7**	23.1	**2.0**	228	0.078	0.40
July 16	21.3	7.9	24.5	3.1	240	0.065	0.30
Aug-16	20.9	7.9	13.9	4.9	238	0.056	0.21
Sept-16	23.0	8.1	12.5	12.0	**112**	**0.026**	0.18
Oct-16	18.2	8.2	12.0	**14.0**	114	0.035	0.19
Nov-16	17.9	**8.4**	13.6	12.0	182	0.031	0.12
Dec-16	16.8	8.2	**11.9**	11.1	195	0.039	**0.11**
Jan-17	**16.1**	8.2	12.8	13.2	189	0.041	0.14

WT-Water temperature, pH, DO-Dissolve oxygen, Free CO_2, TA-Total alkalinity, Phosphate $(PO4)^{3-}$ and Nitrate (NO^{3-})

Total Alkalinity: Carbonates and bicarbonates are the major constituents of lake water, and their concentrations are expressed as total alkalinity The minerals in water from the soil, atmosphere and waste discharge provide the source of alkalinity. Similarly, the ranges observed were between 112 mg/l (September) and 260 mg/l (May) in Ganai (2010), Parveen (2010). The amount of nitrate and phosphate in the present investigation was relatively low. Moderate values of nitrate (0.11-0.42 mg/l) and phosphate (0.026-0.080 mg/l) were recorded, which are similar to the results of Tripathi (2016) and Vatandoost *et al*. (2018).

Aquatic insect larvae (order Diptera and Coleoptera) population:

Aquatic insect populations occur in diverse groups in most ecosystems. Aquatic insects play an important role in preserving the health of water bodies, and their abundance and diversity provide information about the nature of aquatic ecosystems. The present study revealed the presence of 10 genera of aquatic insect larvae (fig. 1). The order Diptera included *Anopheles larvae, Culex larvae, Eristalis larvae, Trichoptera larvae, Chironomus larvae, Psychoda larvae, and Dixa larvae*, and the order Coleoptera included *Hydroporus larvae, Helichus larvae and Cybister larvae.* Dipteran aquatic insect larvae have been found to be dominant. The occurrence of *Eristalis larvae, Trichoptera larvae* and *Chironomus larvae* indicated the polluted nature of the lake. The odonate larva uses *Anopheles larvae* as food and controls Mosquito's population, which is responsible for the spread of epidemic illnesses such as malaria (Prakash (2017), Prommi and Payakka (2015), Saeidi and Vatandoost (2018). Aquatic insect larvae are primary bioindicators of freshwater bodies due to their different environmental tolerance levels (Parveen, *et al.,* 2010; Sharma, *et al.,* 2010). During the present investigation, Chironomus was prominently observed at the village site, where a greater amount of sewage water entered the village site, indicating heavy contamination of the effluent by Culex and Anopheles larvae.

Figure 1: Satellite image of Pardi Lake

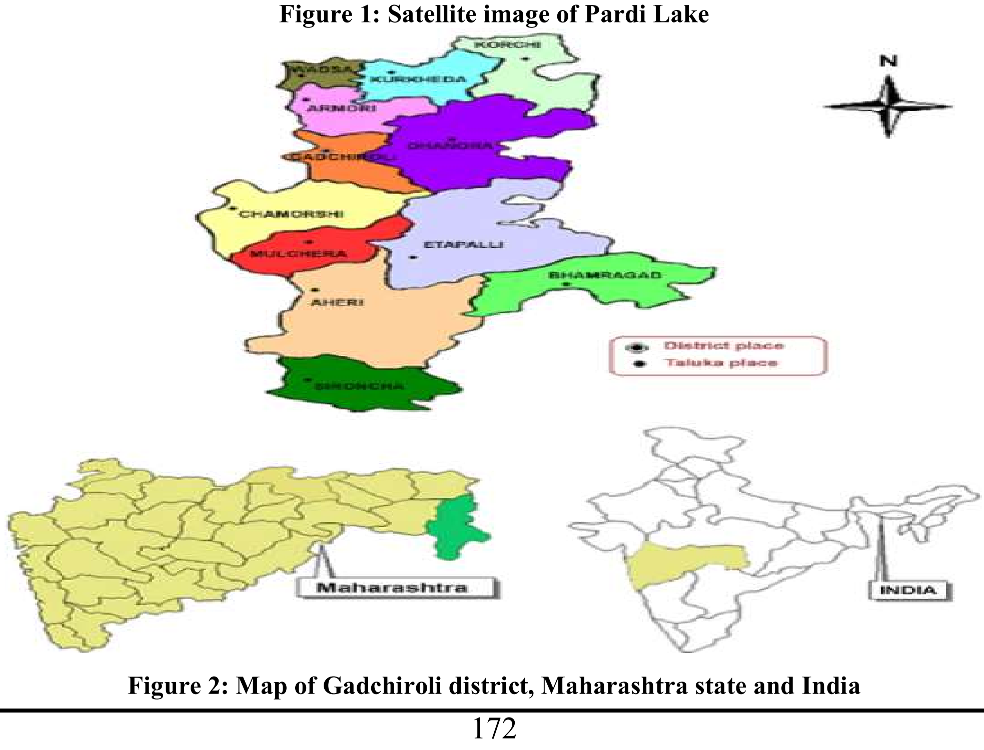

Figure 2: Map of Gadchiroli district, Maharashtra state and India

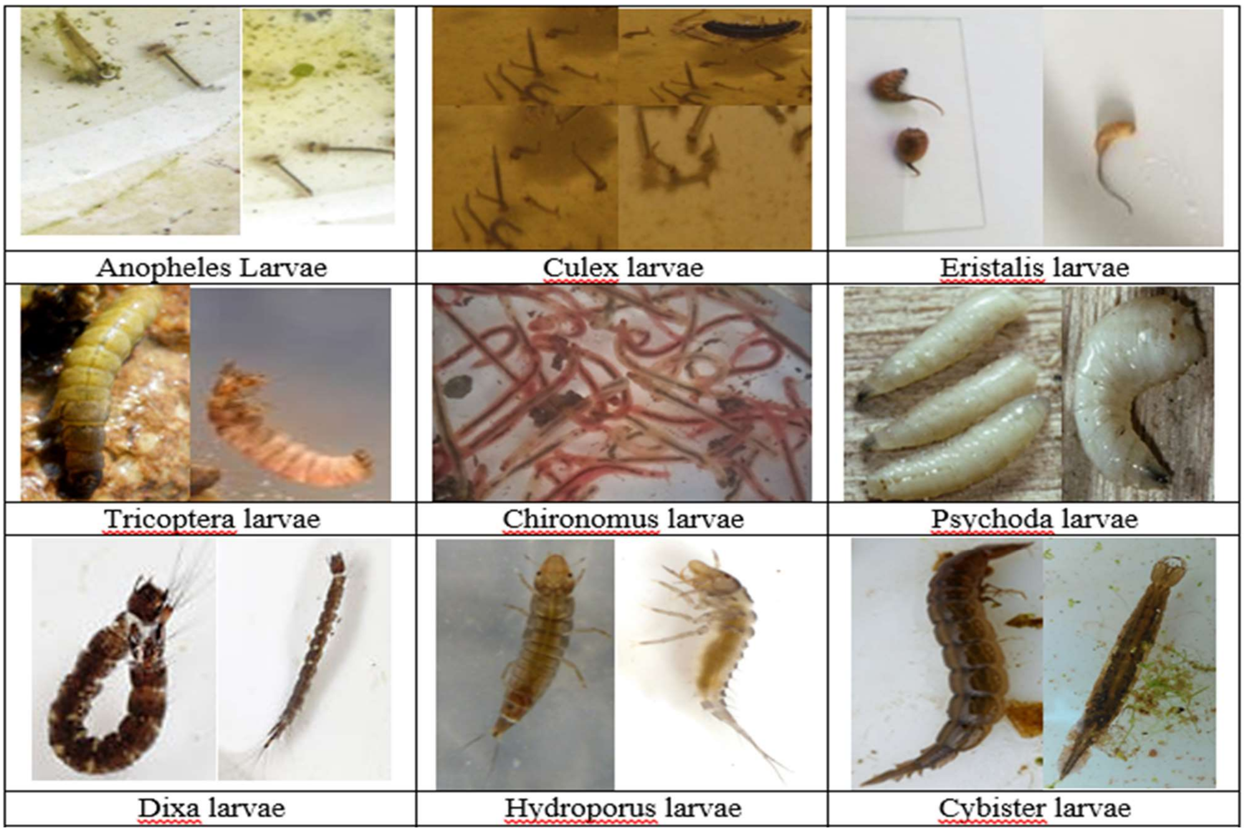

Figure 3: Aquatic insect larval population at Pardi Lake, Gadchiroli, during Feb. 2016-Jan. 2017

Water quality parameters and aquatic insects: The physico-chemical parameters did not vary widely during the entire study period. Water temperature, pH, phosphates and nitrates are very important for the growth and density of phytoplankton, on which aquatic insect larvae and some higher consumers depend.

Conclusion

The present study revealed that the physicochemical parameters studied showed little variation. Aquatic insect communities are useful as faster and less expensive tools for rapid assessment of lake water quality. Mosquitoes and a number of aquatic insect larvae are used as food for fishes and as pollution indicators. Aquatic insects are involved in nutrient recycling and are important elements of natural food web in aquatic ecosystems. In view of the above, such research could provide a better representation of aquatic insect communities. Thus, in view of the importance of this study, necessary steps should be taken for the conservation and maintenance of the lake.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Evaluating thermotolerant sunflower genotypes with temperature induction response (TIR) technique

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ABSTRACT

High temperature affects various physiological processes of the plant. Delayed sowing and changing climate both subject the crop to increasing temperatures during the crop growth period. There is a need to take on a technique to screen the wide number of genotypes for high-temperature tolerance. In the present study, a screening protocol was followed based on the principle of "acquired tolerance" in which 47 sunflower seedlings were exposed to sub-lethal heat stress to induce tolerance before subjecting to subsequent lethal stress and the second set were directly exposed to lethal stress. Significant variation was observed for the traits - survival percentage, total seedling length, and seedling weight. Tolerant inbreds were identified using Z distribution and PCA. Results suggested that TIR is a rapid and powerful technique that can be used to screen large number of germplasms to identify thermotolerant lines.

Introduction

Sunflower (*Helianthus annuus* L.) crop is grown worldwide under a wide range of agro-environments. The world Sunflower area accounts for 27.37 m ha, production of 56.07 m t, and productivity of 2049 kg ha^{-1} (FAOSTAT, 2019). India is 0.26 m ha, with a production of 0.22 m t and productivity of 826 kg ha^{-1}. In India, sunflower cultivation is concentrated mainly in the states, of Karnataka, Maharashtra, Odisha, Andhra Pradesh, and Haryana. Sunflower is primarily grown for its edible oil, protein-rich residual cake for livestock as both irrigated and rainfed crop. Because of its low input requirement and limited GHG emission, it is labeled as an "environmentally friendly crop" (Debaeke *et al.*, 2017). Induced stress tolerances to high temperature (HT) are complex traits dependent on many attributes (Harihar *et al.,* 2014). Heat stress (HS) alters the morpho-physiological processes resulting oxidative stress by reactive oxygen species (ROS) (Hasanuzzaman *et al.,* 2012). 25–30°C is the optimal temperature for sunflower germination and growth, while temperatures exceeding 30°C pose stress on the plant (Qadir *et al.,* 2007). The development of a heat-resistant sunflower breeding population is important for sustainable yield under HS. Plants can tolerate heat stress by physical and biochemical modifications by gene expression changes to some extent (Moreno and Orellana, 2011). Plants show strong responses to HS depending upon the duration, extremity, and also surrounding environmental factors, but the traits identification to HS tolerance should be consideration. Plant scientists are aiming to discover the responses that lead to HT and to look into how the crop can be sustained in HT environments. The objective of this study was 1) to evaluate the performance of sunflower inbreds under increasing temperature at the seedling stage and to correlate the

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data with yield under field condition, 2) to investigate variability in the response of inbreds under induced and lethal treatments, and 3) to identify the tolerant lines under heat stress at seedling.

Material and Methods

Plant Material

A set of 47 promising parental lines of sunflower (*Helianthus annuus* L.) genotypes including 42 inbreds and 5 hybrid checks were used as experimental materials to assess their tolerance to temperature at seedling stage.

Experimental conditions

The lab experiment was conducted during *rabi,* 2021 in ICAR-IIOR, Rajendranagar for a period of 7 days using a factorial CRD design to evaluate the thermotolerance in sunflower seedlings of 0.5 cm radicle length, i) control seedlings maintained at 25 ºC ii) induction seedlings were subjected to a sub-lethal level of temperature stress from 35ºC for 1h, 40ºC for 2h and 45ºC for 1h (induction treatment) and then to a subsequent lethal level of 49ºC for 2h and allowed to recover for 72 hours at room temperature (25ºC) iii) Lethal seedlings with control seedlings directly subjected to the lethal temperature of 49ºC for 2h and allowed to recover (Fig 1). Earlier studies indicate that the TIR technique is an effective technique to identify genotypes tolerant to HT in various crops (Kheir *et al.,* 2012), and therefore, adopted in the present study.

Morphological and yield

Data on morphological parameters such as survival percentage (SP), shoot length (SL), root length (RL), total seedling length (TSL), seedling weight (SW), and seed vigor index (SVI) were noted from 3 randomly selected sunflower seedlings of each genotype in the replication of each treatment and then averaged.

Statistical analysis

The data were summarized using descriptive statistics and analyzed using Z distribution and PCA. The trait's survival percentage and percent reduction in total seedling length are subjected to Z distribution analysis to identify the tolerant genotypes. In PCA the shoot length, root length, seedling weight, and survival measured in different units are standardized to eliminate the scale bias. Based on equation 1, the indices are computed using eigen values and factor loadings obtained from the analysis. Genotypes with the efficient performance of shoot length, root length, seedling weight, and survival are ranked top under induction and lethal treatments. PCA by R (version 3.1.3) was used to characterize trait variation. IBM SPSS was used for Z distribution and correlation.

$$I=\frac{\sum_{i=1}^{n} Xi\left[\sum_{j=1}^{n}|Lij|.Ej\right]}{\sum_{i=1}^{n}\left[\sum_{j=1}^{n}|Lij|.Ej\right]}$$

Where, I=Index, X_i=i[th] indicator, L_{ij}=factor loading value of the i[th] variable on the j[th] factor, and E_j= eigen value of the j[th] factor.

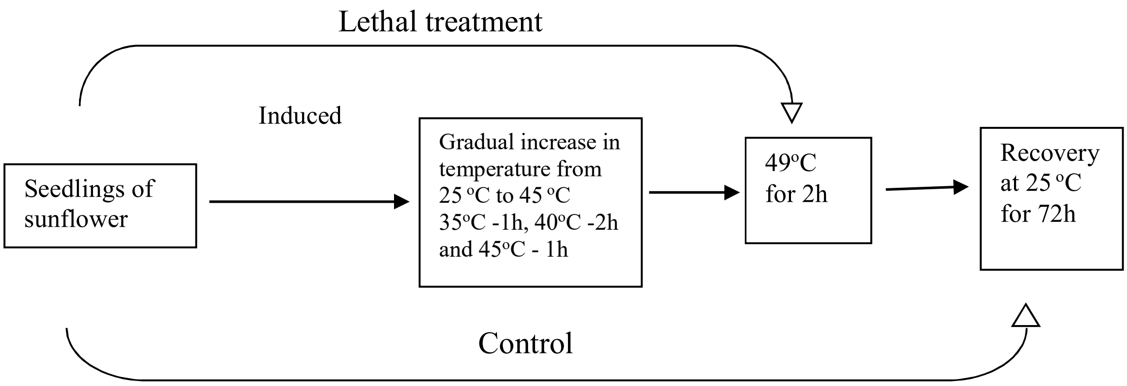

Fig 1. Protocol to study high-temperature stress tolerance through TIR technique

Results and Discussion

Among the 47 sunflower genotypes evaluated, the reduction in growth ranged from 24% in CMS 2023B to 82% in ARM 248B. CMS 2023B showed less reduction in recovery growth when compared to other lines. The induced seedlings of 47 genotypes performed better than the lethal seedlings as they are exposed slowly to the lethal temperature. TIR is a good technique to evaluate the genetic variability for HT tolerance from the earlier studies (Harihar *et al.,* 2014, Kheir *et al.,* 2012).

Genetic variability in sunflower upon induction treatment

Significant variation was observed among the temperature treatments, genotypes and interaction or the trait's SP, RL, SL, TSL, and SW. The genetic variability for thermo tolerance among the 47 sunflower genotypes was analyzed through Z distribution in which the whole set of genotypes is distributed into four different quadrants. Quadrant I included the genotypes with highest SP over control and are considered tolerant while quadrant IV has a higher reduction percent in growth and is considered the most susceptible. CMS lines-17B, 58B, 59B, 127B, 135B, 144B, DSF2B, NDCMS 4B, NDL 3B, HA 291B and check DRSH 1 were grouped in quadrant I and showed a low reduction in growth and higher survival percentage (Fig. 2). Genotypes grouped in Quadrant II had the highest percent reduction, while genotypes grouped in quadrant III had a low survival percentage compared to the control, therefore, these were considered moderately tolerant genotypes. Genotypes AKSF 6-3B, CMS lines-107B, 108B, 122B, 234B, 275B, 302B, 519B, 607B, 850B, 2023B, Pet 2-7-1B, ARM lines-240B, 243B, HA 248B, HA 292B, NDL lines 5B, 6B, 7B, checks CO-2, CSFH 12205, KBSH 44 were grouped in quadrant II and III. The genotypes CMS lines-11B, 38B, 42B, 70B, 103B, 104B, 125B, 853B, NDCMS 2B, ARM lines- 248B, 249B, FMS 400B were grouped in quadrant IV as susceptible genotypes. The genotypes falling in quadrants I and IV distinctly differ in thermo tolerance. The genotypes classified based on Z distribution is presented in Supplementary table 1.

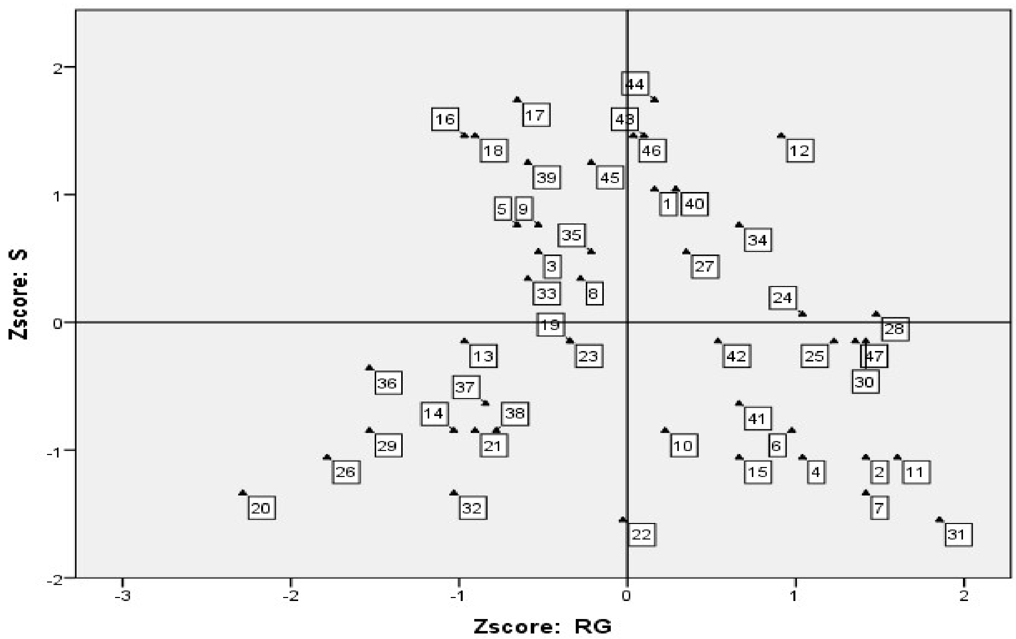

Fig 2. Classification of sunflower genotypes

Table 1 Genotypes found tolerant in Z distribution and PCA

Z distribution			PCA		
Tolerant	**Moderately tolerant**	**Susceptible**	**Control**	**Induction**	**Lethal**
CMS 17B	AKSF 6-3B	CMS 11B	CMS 42B	**CSFH 12205**	**NDL 6B**
CMS 58B	CMS 107B	CMS 38B	CMS 107B	**CO 2**	**CMS 17B**
CMS 59B	CMS 108B	CMS 42B	KBSH 44	**CMS 127B**	**CMS 144B**
CMS 127B	**CMS 122B**	CMS 70B	CMS 850B	**ARM 240B**	**DSF2B**
CMS 135B	CMS 234B	CMS 103B	CSFH 12205	**CMS 58B**	**NDL 3B**
CMS 144B	**CMS 275B**	CMS 104B	AKSF 6-3B	**CMS 17B**	**CMS 58B**
CMS DSF2B	CMS 302B	CMS 125B	ARM 243B	**CMS 135B**	**CMS 275B**
NDCMS 4B	CMS 519B	CMS 853B	CMS 70B	**CMS 59B**	**CMS 59B**
NDL 3B	CMS 607B	NDCMS 2B	CMS 108B	**CMS 144B**	**CMS 122B**
HA 291B	CMS 850B	ARM 248B	DRSH 1	**NDL 3B**	
DRSH 1	CMS 2023B	ARM 249B	CMS 144B		
	COSF 12B	FMS 400B			
	ARM 240B	RSFH 130			
	ARM 243B				
	HA 248B				
	HA 292B				
	NDL 5B				
	NDL 6B				
	NDL 7B				
	CMS Pet 2-7-1B				
	CO 2				
	CSFH 12205				
	KBSH 44				

The %SP varied from 43 to 87% under IT and from 0 to 57% under LT. Among the 47 genotypes screened, 11 showed >75% survival under IT. TSL varied from 4.1 to 12.9 cm under IT and genotypes CMS 108B, 135B, 144B, 275B, 302B, 2023B, ARM 249B, HA 248B, HA 292B, NDL 3B, 5B has shown TSL on par with checks. The %RRG ranged from 16 to 82. The genotypes CMS 275B (16%), and 2023B (27%), showed minimum % RRG (less than 30%), whereas the genotypes CMS 103B (78%), CMS Pet 2-7-1B (76%), NDCMS 2B (75%), CMS 42B (75%), ARM 243B (75%), CMS 853B (72%), recorded a maximum reduction compared to checks. Inbreds CMS 135B and 144B has recorded SP on par with checks and less reduction in SP under IT and LT. Among inbreds ARM 249B (948) followed by CMS 144B (772), CMS 135B (763), and among checks CSFH 12205 (901), KBSH 44 (828) has recorded maximum SVI under IT. A significant positive correlation was observed between SVI and SP after IT indicating the seedling growth performance after the recovery period plays an important role in screening sunflower genotypes (Fig 3). In previous studies also the tolerant, intermediate, and susceptible genotypes were screened based on percent recovery growth. The Z distribution analysis demonstrated a standard method of identifying tolerant genotypes in rice (Vijyalakshmi *et al.,* 2015)

Principal Component Analysis (PCA)

The shoot length, root length, seedling weight, and survival measured in different units are standardized to eliminate the scale bias. The indices are computed through factor loadings and eigen values obtained from the analysis. Genotypes with the efficient performance of SL, RL, SW, and S are ranked top under induction and lethal treatments (Table). Among checks CSFH 12205 (1.2), CO 2 (1.2), and among inbreds CMS 127B (1), followed by ARM 240B (0.9), CMS 58B (0.8), CMS 17B (0.8), CMS 135B (0.7), CMS 59B (0.7), CMS 144B (0.7), NDL 3B (0.6) under induction treatment (Table 3).

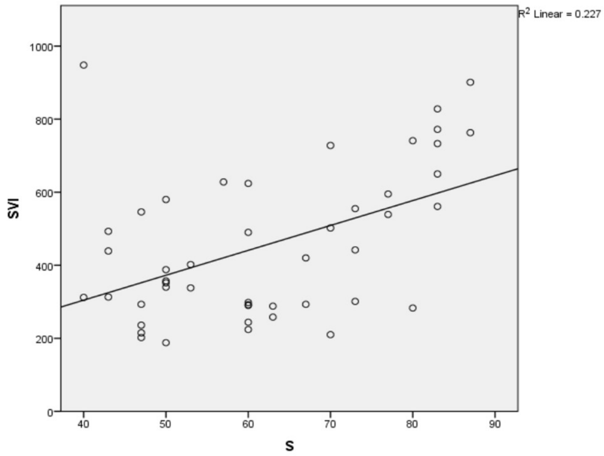

Fig 3. Correlation between seed vigor index and survival

Table 2: PCA index ranks at induction and lethal treatments and seed yield reduction rank under field condition

Ranks									
S.No	Genotypes	Induction rank	Lethal rank	SY rank	S.No	Genotypes	Induction rank	Lethal rank	SY rank
1	AKSF 6-3B	25	27	45	25	CMS 853B	11	9	23
2	NDCMS 2B	41	46	27	26	CMS 2023B	7	7	16
3	NDCMS 4B	18	27	13	27	CMS DSF2B	14	2	10
4	CMS 11B	39	28	9	28	CMS Pet 2-7-1B	14	7	11
5	CMS 17B	6	2	11	29	ARM 240B	3	3	5
6	CMS 38B	37	36	26	30	ARM 243B	15	18	3
7	CMS 42B	37	41	41	31	ARM 248B	17	17	5
8	CMS 58B	5	5	31	32	ARM 249B	6	4	11
9	CMS 59B	6	6	38	33	HA 248B	10	11	1
10	CMS 70B	33	20	9	34	HA 291B	6	9	9
11	CMS 103B	30	24	3	35	HA 292B	7	12	9
12	CMS 107B	26	22	32	36	NDL 3B	3	2	1
13	CMS 108B	21	10	29	37	NDL 5B	4	3	3
14	CMS 122B	16	6	17	38	NDL 6B	5	1	5
15	CMS 125B	27	26	19	39	NDL 7B	3	4	7
16	CMS 127B	3	14	31	40	COSF 12B	6	6	2
17	CMS 135B	4	13	29	41	FMS 400B	6	6	4
18	CMS 144B	4	2	30	42	104B	5	6	4
19	CMS 234B	10	16	12	43	CO 2	2	3	5
20	CMS 275B	5	4	21	44	CSFH 12205	1	1	2
21	CMS 302B	9	24	27	45	DRSH 1	1	1	2
22	CMS 519B	23	6	5	46	KBSH 44	1	2	2
23	CMS 607B	16	19	2	47	RSFH 130	1	1	1
24	CMS 850B	20	16	2					

Table 3: Seedling parameters of the selected inbreds and checks under induction and lethal treatments for indexing

Induction treatment							Lethal treatment					
S.No	Genotypes	Shoot length	Root length	Seedling Weight	Surviva l %	Index	Genotypes	Shoot length	Root length	Seedling weight	Survi val %	index
1	CSFH 12205	78.1	24.4	94.8	86.7	1.2	NDL 6B	47.9	71.7	36.5	20	1.2
2	CO 2	92.3	17	92.1	83.3	1.2	CMS 17B	67	20.3	73.8	40	1.1
3	CMS 127B	72.8	46.9	85.5	83.3	1	CMS 144B	70.6	18.7	49	63.3	0.9
4	ARM 240B	98.8	49.5	93.9	50	0.9	DSF2B	32.7	24.4	80.7	56.7	0.8
5	CMS 58B	49.7	54	99.5	66.7	0.8	NDL 3B	47.9	49.5	48	10	0.7
6	CMS 17B	88.3	33.9	76.7	73.3	0.8	CMS 58B	33.9	25.6	86.6	26.7	0.7
7	CMS 135B	79.9	22.4	72.4	86.7	0.7	CMS 275B	41.2	41.4	64.1	10	0.7
8	CMS 59B	56.6	56.3	83	73.3	0.7	CMS 59B	30.1	27.2	74.3	46.7	0.7
9	CMS 144B	86.3	32.3	65.8	83.3	0.7	CMS 122B	39.1	51	42.9	13.3	0.6
10	NDL 3B	73.4	71.1	78.6	56.7	0.6	ARM 240B	43.4	13.7	86.6	23.3	0.5
11	CMS 275B	82.4	86.2	78.8	43.3	0.5	CSFH 12205	47.2	17.2	54.9	53.3	0.5
12	NDL 7B	66.7	38.3	68.9	80	0.5	CMS 519B	31.6	54.2	37.5	16.7	0.5
13	NDL 5B	65.7	55.9	84.3	53.3	0.5	CMS 108B	33.6	36.9	40.2	33.3	0.3
14	CMS 2023B	80.6	72.5	74.1	46.7	0.4	ARM 249B	51.6	12.3	75.6	0	0.2
15	ARM 249B	75.8	55.9	84.3	43.3	0.4	CMS 2023B	33.8	35.2	48.2	13.3	0.2
16	CMS 234B	44	61.7	84	60	0.3	NDL 5B	31.9	33	51.4	16.7	0.2
17	CMS 302B	55	65.6	84.4	50	0.3	CMS 853B	32.8	20.4	67.8	20	0.2
18	NDCMS 4B	54.7	59.4	68	70	0.3	CMS 135B	22.6	18.2	51.2	66.7	0.2
19	HA 291B	40.5	32.5	80.6	73.3	0.3	CMS 127B	35.1	24.8	33	56.7	0.2
20	CMS 122B	62.1	67.1	77.2	50	0.3	CMS Pet 2-7-1B	24.3	34.3	44.1	30	0.1
21	DRSH 1	67.8	26.4	60.8	80	0.3	DRSH 1	35	16.2	47.6	50	0.1
22	CMS 853B	32.4	23.1	94.8	60	0.2	CO 2	35.1	9.8	53.1	53.3	0.1
23	HA 292B	59.7	43	65.4	70	0.2	CMS 70B	43.1	24.9	41.8	20	0.1
24	NDL 6B	50	81.5	74.7	50	0.2	NDL 7B	38.1	18.3	37.1	46.7	0

25	AKSF 6 3B	60.4	25.8	58.3	76.7	0.1	CMS 234B	24.1	25.9	30.8	50	-0.1
26	CMS 108B	51.1	79	58.3	60	0	CMS 107B	43.1	9.6	30.6	56.7	-0.1
27	HA 248B	56.6	57.1	48.9	66.7	-0.2	AKSF 6 3B	22.6	14.2	50.7	46.7	-0.1
28	KBSH 44	57.9	28.2	42.5	83.3	-0.2	NDCMS 4B	32.1	21.7	46.8	16.7	-0.2
29	CMS 607B	36.4	71.6	56.2	60	-0.3	RSFH 130	19.7	27.2	25	50	-0.2
30	DSF2B	47.1	32.6	53	70	-0.3	CMS 11B	38.7	14.2	41.4	20	-0.3
31	CMS 107B	47.5	14.4	46.7	83.3	-0.3	CMS 103B	24.5	11.1	65.3	13.3	-0.3
32	CMS Pet 2-7-1B	34.5	11.6	69.1	63.3	-0.3	HA 291B	23.9	25	30.6	33.3	-0.3
33	104B	49.6	22.2	57.3	60	-0.4	CMS 850B	16.7	32.3	15	46.7	-0.4
34	COSF 12B	39.9	48.7	39.8	76.7	-0.4	KBSH 44	18.9	11.6	36.7	56.7	-0.4
35	CMS 103B	31	13.6	78.3	46.7	-0.5	HA 248B	29	22.3	21.3	33.3	-0.4
36	CMS 125B	54.8	22.3	57.2	46.7	-0.6	CMS 607B	17.4	27.9	28.9	26.7	-0.4
37	CMS 850B	23.1	40.1	52.3	63.3	-0.7	CMS 125B	39.9	17.3	28.1	13.3	-0.5
38	CMS 70B	58	27.2	46.5	50	-0.7	CBE COSF 12B	21.2	14.5	34.3	40	-0.5
39	ARM 243B	25.2	25.1	53.8	60	-0.8	FMS 400B	8.4	14.9	52.1	30	-0.5
40	CMS 38B	41	19.1	54.5	50	-0.8	CMS 38B	30.3	12.4	47.9	3.3	-0.5
41	CMS 11B	53	15.6	51.2	46.7	-0.8	HA 292B	18.9	14	41.8	23.3	-0.6
42	NDCMS 2B	29.6	20.1	60.4	46.7	-0.8	CMS 302B	31.6	10.4	33.3	16.7	-0.7
43	CMS 42B	29.5	21.4	60.6	43.3	-0.9	104B	27.1	9.7	33.7	23.3	-0.7
44	CMS 519B	34	71.7	45.4	40	-0.9	ARM 248B	25.8	7	46.7	3.3	-0.8
45	FMS 400B	42.1	32.7	30	53.3	-1.1	ARM 243B	12.6	18.1	26.4	26.7	-0.8
46	RSFH 130	22.8	30.6	35.4	60	-1.1	CMS 42B	20.8	14.5	24.5	20	-0.8
47	ARM 248B	26.1	9.1	49.3	40	-1.3	NDCMS 2B	22.2	8.6	26.8	10	-1

Among checks CSFH 12205 (1.2), CO 2 (1.2), and among inbreds CMS 127B (1), followed by ARM 240B (0.9), CMS 58B (0.8), CMS 17B (0.8), CMS 135B (0.7), CMS 59B (0.7), CMS 144B (0.7), NDL 3B (0.6) under induction treatment (Table 3), checks CSFH 12205 (0.5) and among inbreds, NDL 6B (1.2) followed by CMS 17B (1.1), CMS 144B (0.9), CMS DSF2B (0.8), NDL 3B (0.7), CMS 58B (0.7), CMS 275B (0.7), CMS 59B (0.7), CMS 122B (0.6) under lethal treatment (Table 1) recorded higher index of >0.5. Genotypes that were found tolerant in PCA were found moderately tolerant to tolerant under Z distribution (Table 3).

Survival and recovery growth

Different abiotic stresses affect crop growth and productivity thus reducing the yield. Over the years considerable efforts have been made to determine the adaptive mechanism of crops to heat stress and to identify traits, which would help in the selection of identification of tolerant genotypes for temperature stress. In the present study, despite the exposure of inbreds to IT and LT, the survival percentage differed amongst the inbreds (Table 2) because of variations in the stress adaptive mechanisms for thermo tolerance among the genotypes. Earlier standardized the TIR protocol has been modified (ACRIP annual report 2014-2015) for sunflower. The modification was followed to screen 42 inbreds and 5 checks of sunflower in the present study for cellular level tolerance. A similar study was conducted in other crops such as groundnut, cotton (Kheir *et al.,* 2012), and banana (Vidya *et al.,* 2017). In field conditions, plants acquire thermotolerance to go through subsequent LT as in pulses (Partheeban *et al.,* 2017), sunflower (Senthil Kumar *et al.,* 2007). The higher TSL of induced seedlings as a consequence of altered metabolism is seen in a sunflower (Senthil Kumar *et al.,* 2007), Several physiological and biochemical processes occur in response to IT. Further, the threshold temperature for induction and lethal tolerance differs among species as in sunflower, 49ºC for 2 h (Senthil Kumar *et al.,* 2007), in genetic variability for acquired thermotolerance can be observed after exposure to IT for the traits SP, TSL, and SW (Table 3). IT alters the gene expression and thus accompanies greater adaptation and genetic variability to HT (Table 3). This could be due to the different inbreds used which vary in their acquired thermotolerance, which plays an important role as reported in sunflower (Senthil-Kumar *et al.,* 2007); cotton (Kheir *et al.,* 2012). As expected, differences in stress response were noticed among sunflower genotypes. Genetic variation in SP during recovery from LT ranged significantly (P< 0.01) from 0 to 66.7 % in non-induced seedlings and 40 to 86.7% in induced seedlings. The genetic variation in SL and SW has shown the same trend. The variability in basal tolerance was narrow for the trait's SL and SW, while the variability in acquired tolerance was narrow for SP (Table 3). The thermotolerant genotypes selected based on the TIR technique have less yield reduction in field conditions under HT indicating their tolerance at the plant level;. Selection based on SP, TSL, and %RG at the seedling stage is more convenient as it is a reflection of the sum of variation in intrinsic tolerance brought by different tolerance mechanisms (Senthil-kumar *et al.,* 2007). With IT, CMS 135B (87%), CSFH 12205 (87%), KBSH 44 (83%), CO 2 (83%), CMS 107B (83%), CMS 127B (83%), CMS 144B (83%), DRSH 1 (80%), AKSF 6-3B (77%) has recorded survival percentage of >75% indicating the effect of IT on the survivability even at LT. The use of the TIR approach is relevant only when there is adequate genetic variability in the genotypes under study.

Table 3: Genetic variability in thermo tolerance among 47 sunflower genotypes

	Survival (%)		Seedling length		Seedling weight	
	Induced	Non-induced	Induced	Non-induced	Induced	Non-induced
Mean	62.1±2.1	30.8±2.6	7.2±0.3	4.1±0.2	1.3±0.1	0.9±0.04
Max	86.7	66.7	12.9	7.1	2.5	1.6
Min	40	0	3.4	1.6	0.6	0.3

Conclusion

Here we demonstrate the TIR technique as a reliable and rapid screening technique for the preliminary evaluation of the large number of sunflower genotypes for heat tolerance at a very early stage and to assess the genotypic variability in acquired thermotolerance. It helps to narrow down the genotypes by grouping them into tolerant, moderately tolerant, and susceptible genotypes. In this investigation using the TIR approach it is found that AKSF 6-3B, CMS lines 59B, 107B, 127B, 135B, and 144B were consistently found as tolerant and inbreds HA 248B, CMS lines 103B, 607B as susceptible for HT stress. Using this technique it was also evident that there is sufficient genetic variability present among sunflower lines at 49 ºC. Lines found tolerant to high temperatures are useful in breeding programs seeking to overcome this yield limitation. Tolerant inbreds can be studied further to identify the candidate genes for high-temperature tolerance.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Studies on floral morphology and fruit diversity in wild melon (*Cucumis melo* L.ssp. *agrestis* (Naudin) Pangalo var. *agrestis* Naudin)

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ABSTRACT

Floral morphology and fruit diversity are two essential attributes of a plant to establish mutualistic association with pollinators. Pollinators will have a direct influence on fruit setting and yield. The present paper represents the floral morphology and fruit diversity of six wild melon genotypes (*Cucumis melo* ssp. *agrestis*). The staminate and pistillate flowers were analysed for their size, sepal and petal colour and pedicel length. It was observed that female flowers of wild genotypes were longer than male flowers, however male flowers possessed larger diameter, longer pedicel length and corolla length over female flowers. Among the six genotypes studied, HUB-13 produced maximum male flowers per vine (156.75), longest female flower (5.33 cm), longest pedicel and corolla and largest ovary (6.11 mm diameter). Genotype HUB-4 produced maximum female flowers per vine (39.50) with lower male to female sex ratio (2.65:1) and recorded longest male flower length (4.43 cm). Genotype, HUB-2 recorded lowest flower length (2.40 cm, 2.85 cm) and diameter, smallest corolla length (1.25 cm, 1.13 cm) and pedicel length (1.05 cm and 0.50 cm) for male and female flowers respectively. The sepals and petals were green and yellow in colour respectively with varied intensity. The genotype, HUB-9 recorded maximum ovary length (1.83 cm), fruit weight (86.03 g), fruit yield per vine (1.98 kg) and fruit yield per hectare (9.48 t/ha).

Introduction

The efforts to conserve vulnerable plant species is a continuous and never ending process. A successful conservation scheme must take into account the fundamentals of their reproductive cycle. According to Marbaniang *et al.* (2018), the field of reproductive biology covers flower morphology, floral biology, pollination dynamics, fertilisation and embryogenesis, seed development, and germination. Floral morphology plays an important role in attracting pollinators and their frequency of visit (Marten-Rodriguez *et al.*, 2009). Pollinators mostly visit flowers based on colour, scent, quality and quantity of nectar and pollen rewards of flowers (Aronne *et al.*, 2012; Raguso and Willis, 2002). Flower morphology and plant- pollinator mutualism is well studied in wild plant species but it is rarely focused on cultivated plants although it has potential impact on crop yield (Courcelles *et al.*, 2013).

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Variation in floral morphology among genotypes and cultivars is expected to affect visiting rates of pollinators which in turn affect yield (Pyke, 1984). Wild melon belongs to Cucurbitaceae family, with chromosome number 2n=24. Other names for it include wild melon, little gourd, senat seed, and wild musk melon. It is a monoecious annual vine plant with drooping blooms. Between the months of March and June, flowers bloom. It is indigenous to African countries and is grown indiscriminately. It is grown as an intercrop with sorghum in northern Karnataka on marginal soils with minimal crop husbandry. This underutilised cucurbit has attained a position of great value and taken pride of place in rural traditional cuisine because of its palatable flavor, vibrant colours (green, yellow, saffron, red, etc.) and nutritional profile (Kouonon, 2009). Fruits used as salad, for pickles and seeds are rich in edible oils which possess antioxidant and analgesic activities (Gill *et al*., 2011).India is regarded as the primary centre of origin for cucumbers and secondary centre of origin for melons (Zeven and de Wet, 2010). According to Chakravarthy (1982), the genus *Cucumis* includes the cultivated cucumber (*Cucumis sativus* L.) and melon (*Cucumis melo* L.) species as well as the wild species *C. prophetarum*, *C. callosus*, *C. hystrix*, *C. setosus*, and *C. sativus* var. hardwickii. Melons that grow in the wild have unique morphological and agronomic traits, as well as pest and disease resistance that could be explored in breeding programme. Recently, the gene from C. *melo* ssp. *agrestis* has been utilized for closterovirus resistance in *Cucumis melo* (Hofstede *et al*., 2011). Knowledge on floral morphology is vital in crop improvement, to enhance plant- pollinator efficiency and to get high fruit set (Dhall *et al*., 2011). In order to gain further insight into floral morphology and fruit diversity to be explored in breeding programme an experiment was carried out to study floral morphology and fruit diversity of six wild melon genotypes.

Materials and Methods

Experimental area, season and planting material

The experimental area is located 533 meters above MSL with 16.18 degrees North latitude and 75.07 degrees East longitude in the Northern Dry Zone of Karnataka. The experiment was conducted during summer season of 2022 in the Department of Vegetable Science field at the College of Horticulture, Bagalkot. The observations on floral and fruit diversity studies were recorded on six promising wild melon genotypes belonging to the collections of the Department of vegetable science, UHS, Bagalkot *viz*., HUB-2, HUB-4, HUB-9, HUB-12, HUB-13, HUB-14 suited for summer (January-May 2022) cultivation. The metrological data prevailing during the research period is given in appendix 1. The experiment was laid out in RCBD with 4 replications. All the agronomical practices were adopted as per the recommendations of package of practice followed for pumpkin (Anon., 2019). The recommended NPK used for the study was @ 100:60:100 kg NPK per hectare.

Land preparation, transplantation and cultivation

The experimental plot was ploughed and the soil was brought to fine tilth. Flat raised beds were prepared at a distance of two metres apart and manure and fertilizers were applied. Vermicompost @ 2 tonnes per hectare and 50% of the nitrogen in the form of urea, a full dose of phosphorus and potassium in the form of single super phosphate and muriate of potash was used. For irrigation, one inline dripper lateral having emission points at 30 cm apart with a discharge rate of 2 litres per hour was installed in the middle of the bed. Polythene mulch measuring 1.00 m in width and 30 microns thick was covered on the raised beds. On the mulch film, holes of a diameter of 5 cm were drilled at intervals of 1 m. One day before transplanting beds was irrigated to field capacity. 14 days old melon seedlings that were raised in pro trays filled with well decomposed coco peat were transplanted onto individual plots maintaining spacing of 2 m x 1 m. Soon after planting, light irrigation was provided. At 30 days after sowing remaining urea was applied to plants. In order to preserve the ideal plant population of uniform age, gaps were filled within four days after transplantation. Depending on the moisture of the soil, drip irrigation was provided to the crop. Weeding was done at regular intervals to keep the experimental plot free from the weeds (Anon., 2019). Fruits were harvested when they reached the ideal stage of picking at different intervals.

Observations recorded

By using the descriptors provided by National Bureau of Plant Genetic Resources (NBPGR)

(Srivastava *et al*., 2001) and International Plant Genetic Resources Institute (IPGRI, 2003) observations were recorded from five selected plants from each replication on flower morphology parameters *viz*., calyx length (cm) and colour, corolla length (cm) and colour, ovary length (cm) and diameter (mm), flower length (cm) and diameter (cm), pedicel length (cm), number of male flowers per vine, number of female flowers per vine, female: male ratio, quantitative fruit parameters *viz*., fruit length at marketable stage (cm), fruit diameter at marketable stage (cm), fruit weight (g), fruit yield per vine (kg), fruit yield per hectare (t/ha) and the average of five plants were statistically analysed using Fisher's method of "Analysis of variance" as described by Sundararaj *et al*. (1972).Numbers of male and female flowers produced per vine from first flowering to end of blooming season was recorded and the data was used to compute the female: male ratio. Mean of five flowers from each replication was taken to compute calyx length (distance between the junction of the pedicel and the tip of the longest lobe), corolla length (distance between the base of the petals and the distal part of the flower), ovary length, flower length (distance between the pedicel base and the corolla tip), flower diameter and pedicel length by using a measuring scale. Ovary diameter was measured using vernier calliper. Calyx colour, corolla colour, flower colour was noted by visual analysis using a typical Royal Horticulture Society colour chart (Voss and Hale, 1998). Fruit length was measured by using measuring scale and fruit diameter by using vernier calliper. Mean of five fruits was used to measure fruit weight by using weighing balance. After harvesting all fruits from all pickings of a vine fruit yield per vine was computed and this data was used to calculate fruit yield per hectare.

Results and Discussion

Floral morphology

The number female flowers produced by the wild genotypes of melons were lesser than male flowers. The maximum male and female flowers per vine were observed in Hub-13 (156.75) and Hub-4 (39.50), respectively. The male: female ratio was very wide, 2.65 - 4.91: 1 (male to female flowers). As for as sex ratio (Table 1) concerned, the genotype Hub-4 recorded lowest sex ratio (2.65) and differed significantly from other genotypes. The variation in sex ratio of different genotypes of wild melon may be due to variation in plant growth, vigour and environmental conditions in growing area andvariable response to existing environmental conditions. The condition with lower sex ratio is advantageous and economical as it results in higher fruit set and yield (Ullah *et al*. 2011).Evaluation of flower length, flower diameter and petal length of floral parts evidenced that female flowers of wild genotypes were longer than male flowers, whereas male flowers were larger in diameter, corroborating the similar pattern observed in lesser-known melons by pandey *et al*., 2021 and flowers of monoecious plants were larger that allocated more resources to floral parts than bisexual flowers (Costich and Meagher 2001). In terms of flower length (Table 2), the male flowers of HUB-4 (4.43 cm) were longest compared to HUB-13 (4.41 cm), and HUB-9 (4.08 cm) and they were significantly superior over other genotypes, albeit not being different from one another (CD=0.78). Regarding the female flowers, HUB-13 (5.33 cm) was the longest and significantly different from other genotypes. The shortest male and female flower lengths were observed in HUB-2 (2.40 cm, 2.85 cm respectively). As for flower diameter (Table 2), the male and female flowers of HUB-13 (4.58 cm, 4.43 cm respectively) were largest and significantly different from other genotypes. The shortest male and female flower diameter observed was in HUB- 2 (3.35 cm, 2.63 cm respectively). There was considerable variation observed for size of both male and female flowers among genotypes indicating evolutionary modification of these genotypes. The variation in flower length and diameter may be their genetic character of respective genotypes and Fig. 1 shows the genotype variation for flower morphology. Larger flower diameter could be more attractive to pollinators as it provides larger area for landing which ultimately result in effective pollination (Kiill *et al*. 2012). The primary attraction for pollinators depends on flower size (in terms of length and diameter), shape and colour which play a key role in reproductive success of crops (Hein, 2009). Regarding corolla length (Table 2), the male and female flowers of HUB-13 (2.33 cm, 2.10 cm respectively) were largest and significantly superior over other genotypes.

Table 1: Number of male and female flowers per vine and sex ratio of different wild melon genotypes

Genotypes	Number of male flowers per vine	Number of female flowers per vine	Sex ratio
HUB-2	119.25	30.50	3.91
HUB-4	102.00	39.50	2.65
HUB-9	109.00	33.00	3.40
HUB-12	141.75	28.88	4.91
HUB-13	156.75	38.33	4.09
HUB-14	100.75	28.86	3.47
Mean	**121.58**	**33.18**	**3.74**
S.Em ±	1.94	1.17	0.08
CD (P=0.05)	5.84	3.53	0.24

Table 2. Flower length, flower diameter, corolla length and pedicel length of wild melon genotypes

Genotypes	Flower length (cm)		Flower diameter (cm)		Corolla length (cm)		Pedicel length (cm)	
	Male	Female	Male	Female	Male	Female	Male	Female
HUB-2	2.40	2.85	3.35	2.63	1.25	1.13	1.05	0.50
HUB-4	4.43	4.80	4.23	3.83	2.08	1.80	1.98	1.30
HUB-9	4.08	4.45	3.88	3.45	1.78	1.58	1.55	0.75
HUB-12	3.00	3.38	3.65	3.23	1.50	1.40	1.28	0.58
HUB-13	4.41	5.33	4.58	4.43	2.33	2.10	2.10	1.70
HUB-14	3.10	3.70	3.50	3.30	1.45	1.25	1.20	0.65
Mean	**3.57**	**4.08**	**3.86**	**3.48**	**1.73**	**1.54**	**1.53**	**0.91**
S. Em ±	**0.14**	**0.17**	**0.06**	**0.14**	**0.05**	**0.15**	**0.16**	**0.13**
CD (P=0.05)	**0.43**	**0.52**	**0.18**	**0.42**	**0.15**	**0.46**	**0.48**	**0.38**

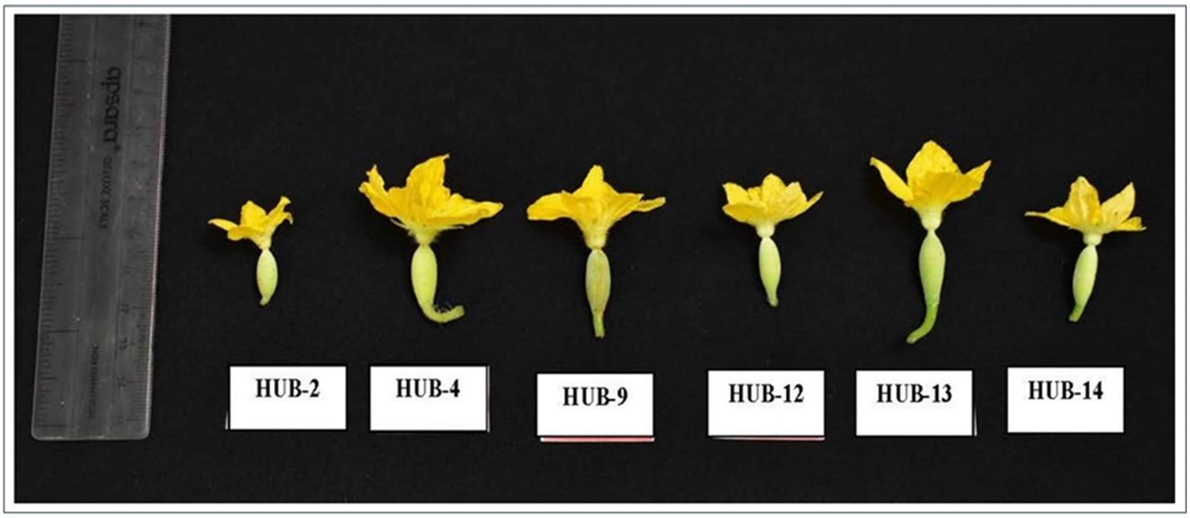

Fig. 1: Genotype variation for flower morphology of wild melon genotypes

The shortest male and female corolla lengths were observed in HUB-2 (1.25 cm, 1.13 cm respectively). Corolla length of male flowers was larger compared to female flowers for all the genotypes, which is similar to findings of pandey *et al.* (2021). There was a positive correlation between petal size and seed set because flowers with larger petals can attract more pollinators or are more successfully pollinated, resulting in more of their ovules being fertilized and developing into seeds (Galen and Newport, 1987). Both staminate and pistillate flowers of all the genotypes contained 5 petals (polypetalous) without variation. Similar results were reported by Pandey *et al.*, 2021. Corolla colour of all genotypes was yellow with varied degree of intensity (Table 3). The attractive nature of yellow colour of corolla may be the genetic character of respective genotypes. Similar observations were reported by Ajuru and Okoli (2013) in *Citrullus lanatus*, *Cucumis melo* and *Cucurbita moschata* and Pandey *et al.* (2021) in less-known melons (*Cucumis melo* L.).In relation to pedicel length (Table 2), the male flowers of Hub-13 (2.10 cm) and HUB-4 (1.98 cm) were found to be longest and differed significantly from other genotypes. Regarding female flowers, HUB-13 (1.70 cm) produced longest flower and it was significantly different from other genotypes. The shortest male and female flower pedicel length was observed in HUB-2 (1.05 cm and 0.50 cm respectively). In all genotypes pedicel length of male flowers were longer than female flowers. This may be an adaptation to attract pollinators since long pedicel allows the flowers to protrude beyond the leaf canopy, improving their visibility to pollinators (Ajuru and Okoli, 2013). Longer the female pedicel length is also easy to harvest as fruits of shorter pedicel hid under the vine (Rasul *et al.* 2004).The calyx colour for the six varieties was observed in the present study according to the standard RHS colour chart described by Voss and Hale (1998) shown in Table 3. Among male flower calyx colour HUB-4 represented in Green group 135A. Genotypes, HUB-2 and HUB-12 represented in Green group 135B and remaining genotypes HUB-9, HUB-14 represented in Green group 135C. With respect to female flower genotypes HUB-4, HUB-12 and HUB-14 have noticed in Green group 136A. Genotype HUB-13 belonged to Green group 136B and HUB-2, HUB-9 belonged to Green group 136C.

Table 3: Colour of calyx and corolla, ovary length and diameter of wild melon genotypes

Genotypes	Calyx colour		Corolla colour		Pistillate flower	
	Male	**Male**	**Male**	**Female**	**Ovary length (cm)**	**Ovary diameter (mm)**
HUB-2	Green group 135B	Green group 135B	Yellow group 7A	Yellow group 7B	1.05	4.57
HUB-4	Green group 135A	Green group 135A	Yellow group 7B	Yellow group 7B	1.45	5.75
HUB-9	Green group 135C	Green group 135C	Yellow group 7A	Yellow group 7C	1.83	5.59
HUB-12	Green group 135B	Green group 135B	Yellow group 7C	Yellow group 7C	1.24	4.58
HUB-13	Green group 135A	Green group 135A	Yellow group 7B	Yellow group 7C	1.43	6.19
HUB-14	Green group 135C	Green group 135C	Yellow group 7A	Yellow group 7B	1.40	4.64
Mean					**1.40**	**5.22**
S. Em ±					**0.18**	**0.06**
CD (P=0.05)					**0.56**	**0.17**

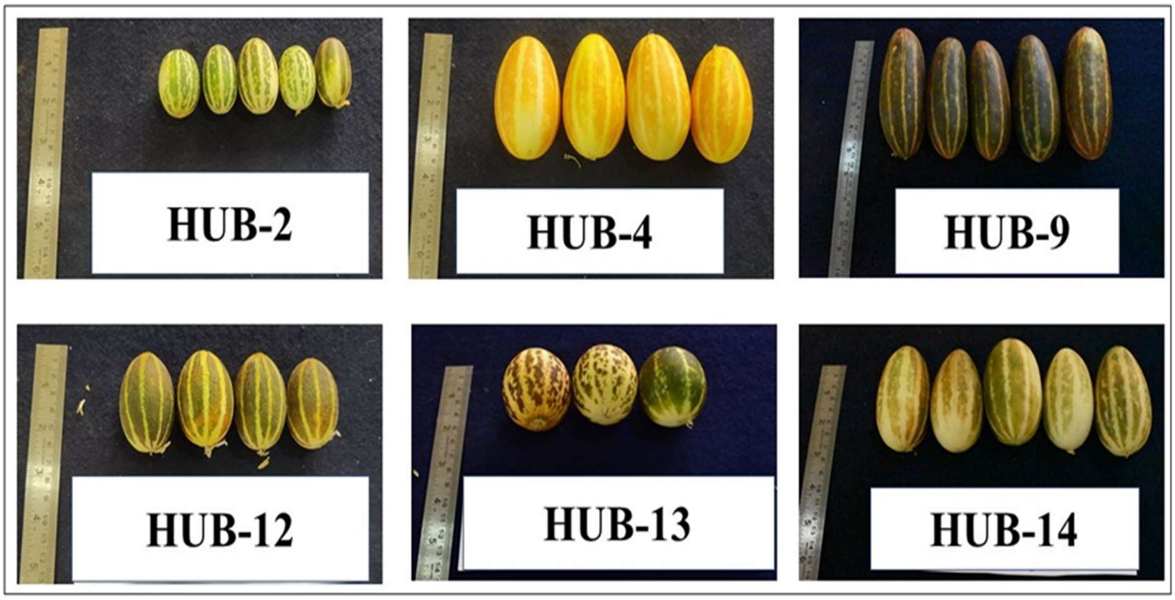

Fig. 2: Genotype variation of fruits of wild melon genotypes

The studied genotypes of wild melon produced green colour calyx, this may due to genetic nature of genotypes. This is in close agreement with the findings of Ajuru and Okoli (2013) in *Citrullus lanatus*, *Cucumis melo* and *C. moschata*. Regarding corolla colour (Table 3), male flowers of HUB-2, HUB-9 and HUB-14 were represented in Yellow group 7A. HUB-4 and HUB-13 genotypes in Yellow group 7B. The genotype, HUB- 12 exhibited Yellow group 7C. With respect to female flowers colour HUB-2, HUB-4 and HUB-14 had exhibited Yellow group 7B. Genotypes HUB- 9, HUB-12 and HUB-13 produced colour of 7C Yellow group (Voss and Hale, 1998). The flowers of different genotypes of wild melons produced attractive yellow coloured corolla, it appears to be the genetic character of the respective genotypes as observed by Ajuru and Okoli (2013) in melons. As for the ovary length (Table 3), the pistillate flowers of HUB-9 (1.83 cm) recorded longest ovary length and HUB-2 (1.05 cm) shortest and there was no significant differences among other genotypes. Regarding ovary diameter (Table 3), HUB-13 (6.19 mm) had recorded significantly biggest ovary diameter compred to other genotypes and smallest was observed in HUB-2 (4.57 mm). The ovary size (length and diameter) has positive correlation with fruit size (Rasul *et al*. 2004).

Fruit characters

There was a significant variation for fruit characteristics among the genotypes (Figure 2). Mean fruit length and diameter of six genotypes was 6.88 cm, 4.63 cm, respectively. With regard to fruit length (Table 4), the HUB-9 genotype recorded the maximum fruit length (9.90 cm) and differed significantly from other genotypes. As for fruit diameter (Table 4), fruits of HUB-13 (5.85 cm) were largest in diameter and significantly different from other genotypes. The lowest fruit length and diameter was observed in HUB-2 (4.60 cm, 3.75 cm, respectively). The genotypes HUB-9 recorded maximum fruit length and HUB-13 recorded maximum fruit diameter. These results are in correspondence with Rasul *et al*., 2004, who observed considerable variations in Twenty-nine genotypes of kakrol (Momordica dioica Roxb.). The mean fruit weight, fruit yield per vine, fruit yield per hectare of six genotypes was 66.20 g, 1.56 kg, 7.78 t/ha, respectively (Table 4). In relation to fruit weight, the genotype HUB-9 (86.03 g) had registered largest fruit weight and differed significantly over other genotypes. Fruit yield per vine and fruit yield per hectare was maximum in HUB-9 (1.98 kg, 9.48 t/ha respectively) and differed significantly over other genotypes. The lowest fruit weight, fruit yield per vine, fruit yield per hectare

Table 4. Fruit yield parameters of wild melon genotypes

Genotypes	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Fruit yield per vine (kg)	Fruit yield per hectare (t/ha)
HUB-2	4.60	3.75	44.33	1.24	6.40
HUB-4	7.25	4.49	63.30	1.49	7.28
HUB-9	9.90	5.17	86.03	1.98	9.48
HUB-12	6.00	3.94	60.15	1.42	6.98
HUB-13	5.23	5.85	77.20	1.63	8.40
HUB-14	7.33	4.60	66.23	1.61	8.18
Mean	**6.88**	**4.63**	**66.20**	**1.56**	**7.78**
S. Em ±	**0.26**	**0.17**	**2.51**	**0.13**	**0.20**
CD (P=0.05)	**0.78**	**0.53**	**7.56**	**0.39**	**0.59**

was recorded in HUB-2 (44.33 g, 1.24 kg, 6.40 t/ha, respectively). Among the six genotypes, HUB-9 had produced maximum fruit yield. This may be due to presence of greater number of perfect flowers per vine, low sex ratio, a greater number of fruits per vine, maximum fruit length, more fruit diameter and high average fruit weight

Conclusion

It is concluded from the studies that among six genotypes, HUB-13 produced biggest flower size and ovary diameter hence attracted maximum pollinators and resulted in maximum fruit set. Genotype, HUB-9 had produced greater number of perfect flowers per vine, low sex ratio, a greater number of fruits per vine, maximum fruit length, wider fruit diameter and high average fruit weight and resulted in maximum yield per hectare. Hence HUB-9 and HUB-13 can be further used for crop improvement and hybridisation works. HUB-4 recorded lowest sex ratio, a desirable character can be used for interspecific hybridisation with other melons for utilization of low sex ratio.

Conflict of interest

The authors declare that they have no conflict of interest.

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Growth and instability analysis of area, production and yield of groundnut in selected states of India

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ABSTRACT

India is the largest producer of oilseeds in the world as oilseed sector occupies an important position in the agricultural economy of the country. The study was based on the secondary data from 2002-03 to 2019-20. Major five groundnut producing states were selected based on highest production last triennium average production. The growth rate and instability were computed by using Compound Annual Growth Rate and Cuddy-Della Valle Index. The growth pattern of groundnut witnessed a downward trend with respect to area except Rajasthan state (7.667%). Growth pattern of groundnut indicated a downward trend in respect to production in Andhra Pradesh, Karnataka and Tamil Nadu state. Growth rate in yield (4.442 %)of groundnut was observed highest in Gujarat state. The instability index showed that the fluctuation in production of groundnut was found to be higher in Andhra Pradesh (44.453%) and Gujarat (41.660%). Low rate of instability was observed in area under groundnut crop in Gujarat (9.690%), Karnataka (10.495%) and Tamil Nadu (11.802%).

Introduction

India produces 10.24 Million Tonnes (MT) of groundnuts, coming in second place to China. Additionally, according to the FAO, 5.96 million ha of India's land were used for groundnut farming in 2021. Gujarat (4.65 MT), Rajasthan (1.62 MT), Tamil Nadu (1.03 MT), Andhra Pradesh (0.85 MT), Karnataka (0.50 MT), Madhya Pradesh (0.35 MT), and Maharashtra (0.31 MT) are the major groundnut-producing states in India in 2019-20 (Anonymous, 2021). India has the best conditions for the cultivation of all nine oilseeds, including seven edible oilseeds groundnut, rapeseed-mustard, sunflower, soybean, sesame and safflower (Thapa *et al.,* (2019). Groundnuts are available all year in India due to a two-crop cycle harvested in March and October. Groundnuts are an important protein crop in India, where they are grown primarily under rain-fed conditions. Nuts are consumed in a variety of forms or crushed to provide vegetable oil for human consumption as well as a protein-rich meal for livestock. Groundnut are also known as earthnuts, pea nuts, goober peas and monkey nut (Misra, 2017). The Technology Mission on Oilseeds (TMO) and the Oilseeds Production Programme (OPP), both started by the Indian government, are the two main interventions that have made a significant improvement to the oilseed industry in India. In May 1986, during the 8th Five-Year Plan, in order to increase national oilseed production and liberalise oilseed trade in the post-WTO era (Nayak *et al.,* 2021). Numerous oilseed crops are grown in various agro-climatic regions, but their growth performance

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is subject to a variety of risks over time and in various agro-climatic locales. Exploiting the yield potential of many oilseed crops is hindered by numerous biotic, abiotic, technological, institutional, and socioeconomic constraints, particularly in the case of groundnut.

Description of the study area

Groundnut is the major oil seed crop in India and it is growing in many states of the country. The states were selected on the basis of their average groundnut production from the year 2017-18 to 2019-20. The selected states namely Gujarat, Rajasthan, Tamil Nadu, Andhra Pradesh and Karnataka (Table 1). The study throws a light on growth and instability in area, production, productivity of groundnut in selected states. Comprehending the growth trends facilitates policymakers' decision making with respect to subsidies, incentives, and farmer support system.

Source of data

The study is based on secondary data of area, production, productivity of groundnut from 2002-03 to 2019-20 (18 years) were collected from Directorate of Economics and Statistics, Directorate of Agriculture, Cooperation & Farmers Welfare, Government of India. Analyzing the growth rate can help farmer's policymakers and other stakeholders identify risks and vulnerabilities in the agricultural sector.

Table 1: Top five groundnut producing states in India

Sr. No.	States	Triennium average production ('000 tonnes)
1	**Gujarat**	3566.649
2	**Rajasthan**	1420.500
3	**Tamil Nadu**	982.840
4	**Andhra Pradesh**	786.790
5	**Karnataka**	480.870

Material and Methods

Compound growth rate analysis

The growth rates refers to the percentage change of a specific variable within a specific period of time. It also indicates the magnitude of the rate of variation in the variable per unit of time. The compound annual growth rate (CAGR) of area, production and productivity of groundnut for 18-year period (2002-03 to 2019-20) were calculated using the following growth model,

$$Y = ab^t u_t \quad (1)$$

Where,

Y = Area, production and productivity of groundnut crop
a = Intercept
b = Regression coefficient
t = Time (years)
u_t = Error term

The equation (1) was transformed as follow:

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

for ease in calculation.

Then, the CAGR was calculated using following relationship

$$G = [(\text{antilog } b)-1] \times 100 \quad (2)$$

Instability Index

Instability index is a simple analytical technique to find out the fluctuation or instability in any time series data (Ramasamy *et al.*, 2005; Gupta and Sharma, 2010). Coefficient of Variation (CV) is the simplest measure of instability in area, production and productivity in selected groundnut states.

$$CV\% = \frac{\hat{\sigma}}{\bar{X}} \times 100 \quad (3)$$

Where,

CV%	=	Coefficient of variation of area, production and productivity
$\hat{\sigma}$	=	Standard deviation of concerned variables
$\overline{X}$	=	Mean value of concerned variable

Though CV is one of the simplest measures of instability, it does not fully explain the variability in time series data due to the presence of the trend component. To address this issue, the formula proposed by Cuddy and Della (1978) was used. Rather than assessing variability over the mean of the data Cuddy and Della consider the data's time trend and measures variability over the time trend. The corrected coefficient of determination is the R^2 coefficient of determination of the linear trend function that fits the time series. The Cuddy-Della instability index was calculated in this manner.

$$CDVI\ (\%) = CV\sqrt{(1-\bar{R}^2)} \quad (4)$$

Where,

CDVI	=	Cuddy – Della Valle Index
CV	=	Coefficient of Variation in per cent
$\bar{R}^2$	=	Adjusted Coefficient of Determination

$$\bar{R}^2 = 1 - \frac{SS_{res}/(n-p)}{SS_{tot}/n-1} \quad (5)$$

When the test statistic t is significant, then the Cuddy- Della Valle index is calculated. When a test statistic is not significant or the adjusted R^2 is less than zero, the CV is chosen. The high value of instability index shows that there were huge fluctuations in the time series data (Table 2).

Table 2: The ranges of instability index

Category	CDVI (%)
Low instability	0.00 – 15.00
Moderate instability	15.01 – 29.99
High instability	≥ 30.00

(Mulla, 2018)

Results and Discussion

Trend analysis is a type of technical analysis that employs time series analysis to comprehend a groundnut crop's past behaviour. The current research phase focuses on a trend analysis of the groundnut area, production and productivity of major groundnut producing states of India.

Gujarat

Gujarat is the leading producer of groundnut with an area of 1690 thousand hectares and production about 4560 thousand tonnes, which occupy 34.989 per cent of area and 45.829 per cent of the total production during 2019-20 in India. Gujarat showed negative growth rate in groundnut area at 1.564 per cent per annum with one per cent level of significance and low rate of instability (9.690 %) during the study period (Table 3 and Fig 1-3). Farmers' adherence to the same crop and lack of change could explain the low rate of instability. Kolar *et al*., (2020) also found low rate of instability in area under groundnut crop during their study period (1995-96 to 2017-18) Groundnut production was 2202.82 thousand tonnes during 2018-19 and it increased and reached at 4560.00 thousand tonnes in 2019-20 due to good rainfall compared to last year. In case of production and yield, it showed 2.774 per cent and 4.442 per cent growth rate, respectively. However, groundnut production and yield registered high rate of instability of 41.600 per cent and 37.303 per cent, respectively. Adverse climatic conditions during the harvesting season contributes a major role in variation in yield and production.

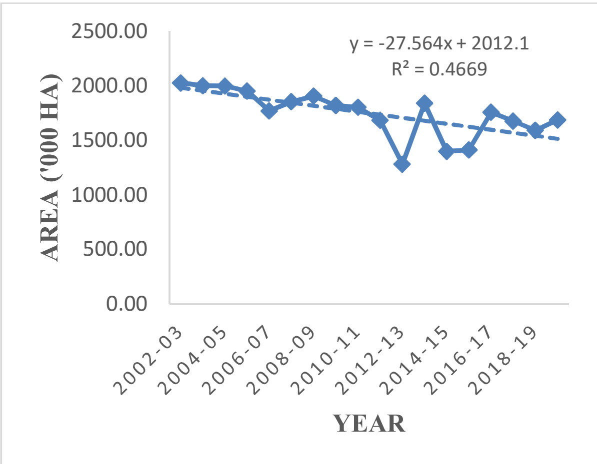

Fig. 1: Trends of groundnut area in Gujarat state

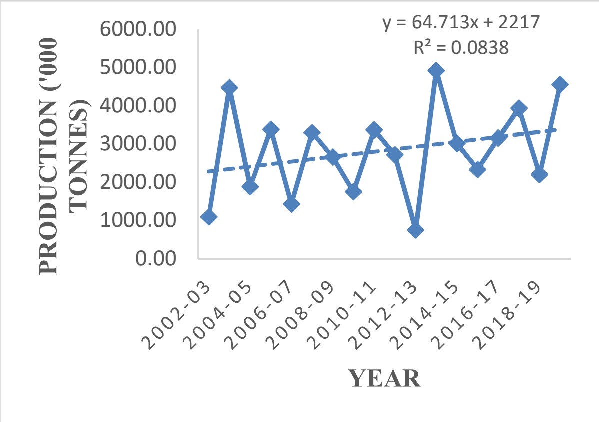

Figure 2: Trends of groundnut production in Gujarat state

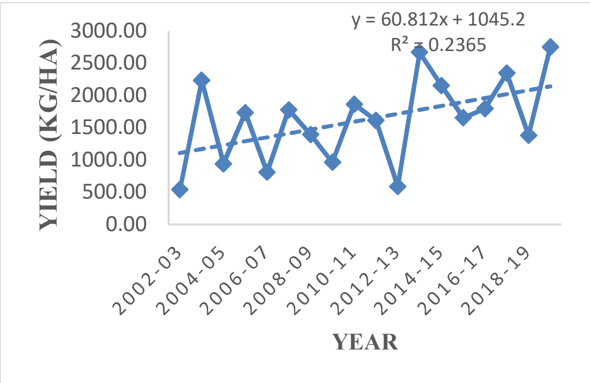

Figure 3: Trends of groundnut yield in Gujarat state

Rajasthan

Rajasthan state has emerged as one of the leading producers of groundnuts in India. In Rajasthan, area and production of groundnut were 740 thousand ha and 1620 thousand tonnes, respectively in 2019-20, which had notable share of 15.320 per cent and 16.281 percent of total area and production of groundnut, respectively in all India. Major groundnut growing districts are Jodhpur, Bikaner, Churu, Jaipur, Jaisalmer, Sikar, Hanumangarh, Sirohi and Nagaur. Area under groundnut crop has been positively increasing at 7.667 per cent per annum and also found statistically significant at one per cent level (Table 3 and Fig 4-6). Groundnut production increased by 11.012 per cent per annum. These results are supporting by Suman *et al.* (2019), who found positive growth rate in production (10.83 %) and yield (3.59 %) of groundnut during their study period 2005-14 in Rajasthan. Area (16.723 %), production (20.216%) and productivity (16.390%) registered medium instability during entire study period. According to Kolar *et al.* (2020), they also found medium rate of instability in both area (18.42 %) and production (25.73%).

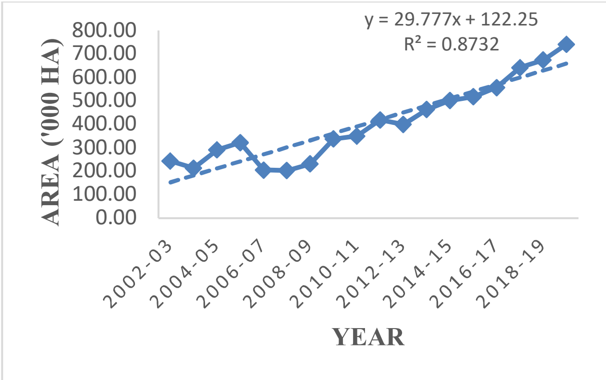

Figure 4: Trends of groundnut area in Rajasthan state

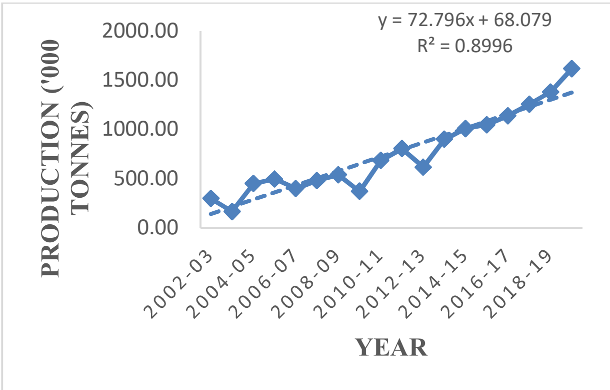

Figure 5: Trends of groundnut production in Rajasthan state

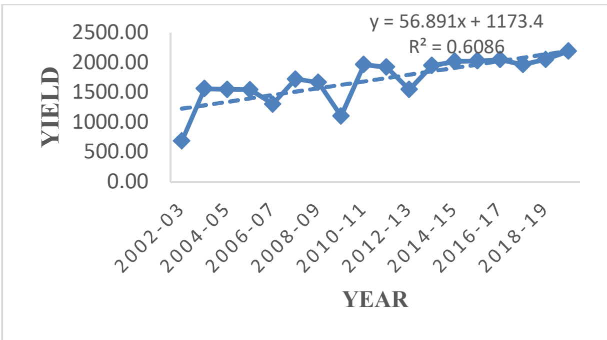

Figure 6: Trends of groundnut yield in Rajasthan state

Table 3: Compound annual growth rate (CAGR) and Cuddy- Della Valle index (CDVI) in area, production and yield of groundnut crop during 2002-03 to 2019-20

States	Area		Production		Yield	
	CAGR (%)	CDVI (%)	CAGR (%)	CDVI (%)	CAGR (%)	CDVI (%)
Gujarat	-1.564**	9.690	2.774	41.600	4.442*	37.303
Rajasthan	7.667**	16.723	11.012**	20.216	3.875**	16.390
Tamil Nadu	-4.109**	11.802	-0.336	14.097	3.958**	10.099
Andhra Pradesh	-5.540**	15.865	-4.289*	44.453	1.506	34.680
Karnataka	-3.568**	10.495	-1.511	22.541	2.133**	16.283

Note: * and ** denotes significance at 5 per cent and 1 per cent levels, respectively.

Andhra Pradesh

Andhra Pradesh is one of the important groundnut producing states in India. Additionally, the Krishna-Godavari delta region as well as the districts of Anantapur, Kurnool, Chittoor, Kadapa, Vizianagaram, and Srikakulam produce groundnuts. Area and production under groundnut crop were 660 thousand ha and 850 thousand tonnes, respectively in 2019-20 and notable share 13.664 per cent and 8.542 per cent of total area and production of groundnut in India. Area and production of groundnut crop both registered significant decrease with 5.540 per cent and 4.289 per cent, respectively (Table 3 and Fig 7-9). The similar results also found by Pusadekar (2018) during their study period (1995-96 to 2015-16), who found that growth rate in area and production of groundnut declined at 3.01 per cent and 2.40 per cent per annum. Groundnut crop production and yield both showed high levels of instability, at 44.453 and 34.680 percent, respectively. Groundnut production is negatively impacted by extreme weather conditions like cyclones, heavy rains, hailstorms, dry spells, drought, and frost.

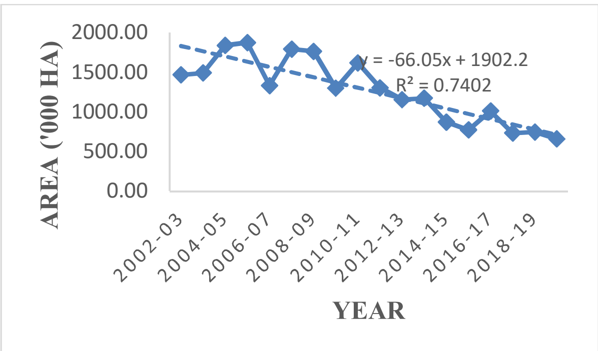

Fig 7: Trends of groundnut area in Andhra Pradesh

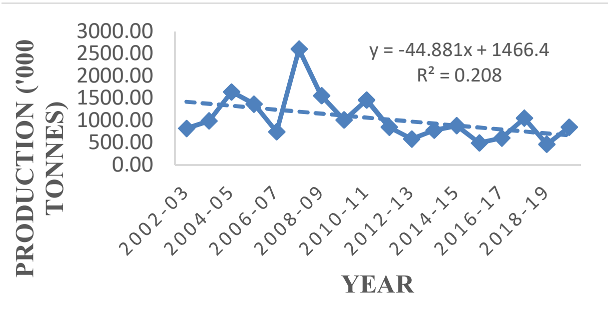

Fig 8: Trends of groundnut production in Andhra Pradesh

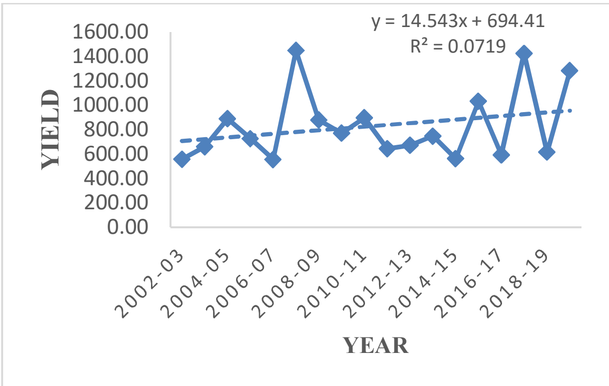

Fig 9: Trends of groundnut yield in Andhra Pradesh

Tamil Nadu

Tamil Nadu is one of the major groundnut producing states as far as productivity is concerned. Major groundnut-growing districts in Tamil Nadu include Namakkal, Salem, Erode, Pudukkottai, Kachipuram, Cuddalore, Harmapuri, Krishnagiri and Ariyalur. Area under groundnut crop in Tamil Nadu has 7.246 per cent share in total area and 10.351 per cent share in total groundnut production of India. Area under groundnut crop was declined at the rate of 4.109 per cent per annum with one per cent level of significance (Table 3 and Fig 10-12). The reason might be area of other crops which grow in same season of groundnut has increased *i.e.* rice, cotton and soy bean. However, production showed negative growth rate at 0.336 per cent and yield registered significant increase with 3.958 per cent growth rate at one per cent level of significance. This results also supporting by Kolar *et al.* (2020) who also observed a negative growth rate in groundnut crop area and production by (- 5.29%) and (-1.46%) respectively, from 1995–1996 to 2016–17 in Tamil Nadu state. Additionally, a low rate of instability was seen in the area, production, and yield during the study period.

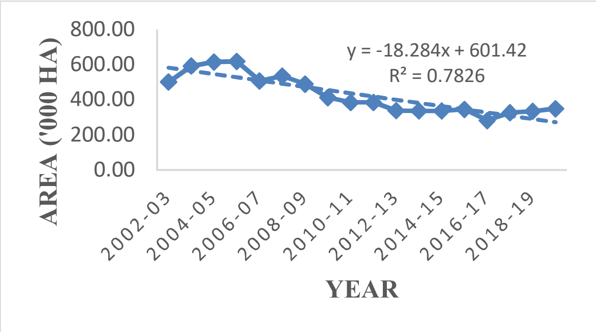

Fig 10: Trends of groundnut area in Tamil Nadu

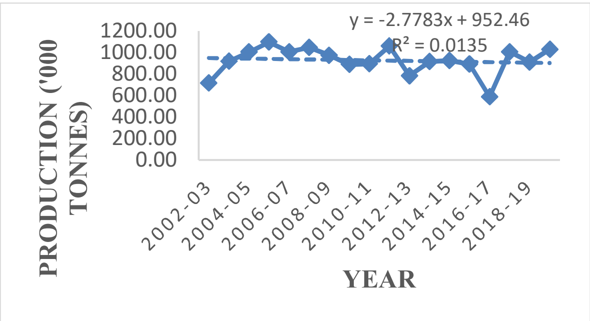

Fig 11: Trends of groundnut production in Tamil Nadu

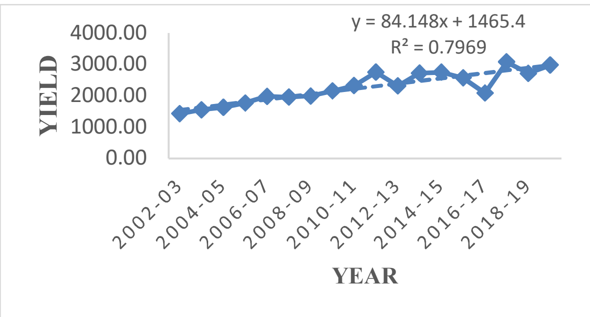

Figure 12: Trends of groundnut yield in Tamil Nadu

Karnataka

In terms of area and oilseed production in India, Karnataka is the second-largest state, followed by South India in terms of area, production, and yield. Area and production under groundnut crop declined at the rate of 3.568 per cent and 1.511 per cent per annum, respectively (Table 3 and Fig 13-15). This results supported by Mulla (2018) who found the area and production of groundnut crops decreased by 1.13 percent and 0.40 percent annually, respectively during the study period (1975–1976 to 2015–2016). Area under groundnut crop had a low rate of instability (10.495%), whereas production and yield had a medium rate of instability (22.541% and 16.283%, respectively).

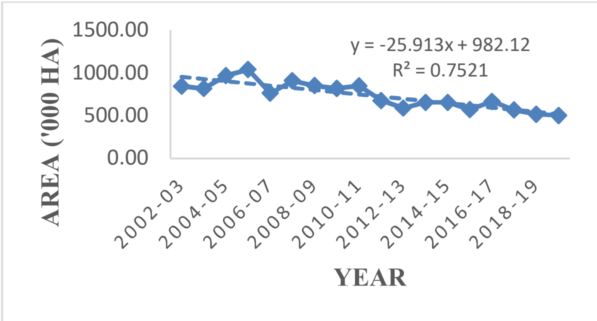

Figure 13: Trends in groundnut area in Karnataka

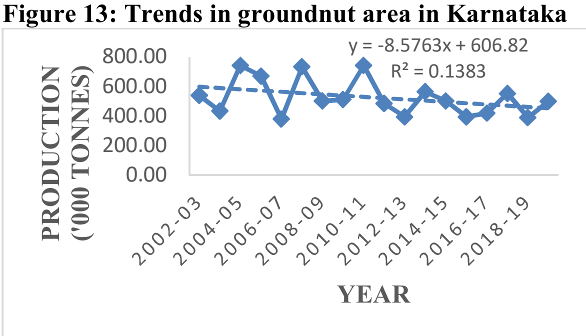

Fig 14: Trends in groundnut production in Karnataka

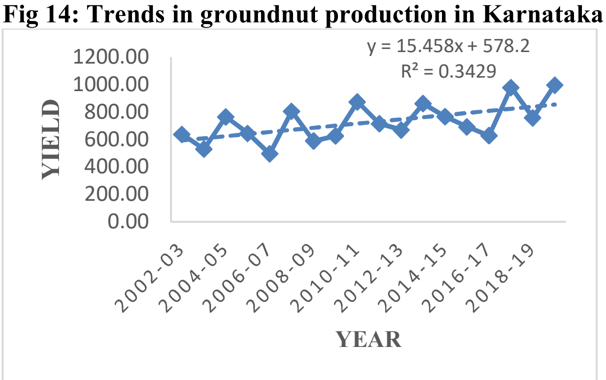

Fig 15: Trends in groundnut yield in Karnataka

Conclusion

The world's largest producer of oilseeds is India. In Gujarat, Tamil Nadu, Andhra Pradesh, and Karnataka, groundnut growth has been declining in terms of area. The rate of instability was low in groundnut crop areas in Gujarat, Tamil Nadu, and Karnataka. Rajasthan had the highest rate of growth in production. According to the findings, researchers and policymakers must pay closer attention to developing location-specific cultural practises in order to increase and sustain groundnut production and yield in the country. Policies and programmes should focus on expanding the area under cultivation to include non-traditional areas in order to increase groundnut production.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Effect of seed priming on germination parameters of Bael (*Aegle marmelos* Corr.) under laboratory conditions

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ABSTRACT

The current experiment was conducted during 2020-21 at the Microbiology Laboratory, CCS Haryana Agricultural University, Regional Research Station Bawal to examine the impact of bio-inoculants and chemicals seed priming on bael seed germination. There were 15 seed priming treatments i.e., control, IBA @ 100 ppm and 50 ppm for 24 hours, NAA @ 50 and 100 ppm for 24 hours, GA_3 @ 50 and 100 ppm for 24 hours, KNO_3 @ 1 per cent for 24 hours, *Azotobacter* (HT 54) for 30 minutes, *Trichoderma viride* for 30 minutes, *Rhizobium* (CK 16) for 30 minutes, PSB (P 36) for 30 minutes, hot water for 30 minutes, nitric acid for 3 minutes, sulphuric acid for 3 minutes. Among different seed priming treatments, shortest germination time (12.7 days) was recorded with sulphuric acid for 3 minutes in agar medium at 28 ºC under laboratory conditions and the highest germination percentage (83.3 %), dry weight per seedling (153.2 mg), seedling length (12.2 cm) and vigour index I (976) and II (12256) were observed when bael seeds primed with GA_3 @ 100 ppm for 24 hours under laboratory conditions.

Introduction

Bael (*Aegle marmelos* Corr.) is an underutilized fruit tree belongs to Rutaceae family. It is a tropical tree native to India and is popularly referred as Indian quince, Bengal quince, Bel, Bilva, Sriphal, Maredo and Stone apple in India. It is sacred tree in Hinduism and Lord Shiva and Parvati offer up its fragrant trifoliate leaves in their prayers. The most important bael growing states in India are Bihar, Orissa, Haryana, Uttar Pradesh, West Bengal and Madhya Pradesh. Bael tree is highly heterozygous in nature (Pati *et al.*, 2008). It is a resilient plant that may flourish in a variety of climatic and soil conditions. Although, it flourishes well in subtropical environment having well-drained sandy loam soil, however, tree grow well on lands which are not suitable for other fruit trees. Plants can tolerate extreme pH ranging from 5 to 10, sodicity upto 30 ESP and salinity 9 ds/m (Saroj *et al.*, 2006). Fruits are well known for its therapeutic qualities due to the presence of marmelosin. Mature fruits are astringent, digestive and stomachic in nature and often used to treat diarrhoea and dysentery. In ethnomedicine, various plants parts have been utilized as astringent, antidysentric, anticancer, antiulcer, antidiarrhoeal, antipyretic, antidiabetic, antiviral, analgesic, antifungal, radioprotective and anti-helminthic (Patkar *et al.*, 2012). Fresh leaves can be utilized as medicine for asthma, dropsy, cataract and beriberi (Maity *et al.*, 2009). In its root extract, anti-inflammatory and wound-healing

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properties are found. Bael is typically propagated by seeds and seedlings raised are not true to type and show great degree of variations. Although seedling raised trees produce fruit of varying size and quality, but they usually take long time to start bearing. Nearly 660-hectare area increases from 2020 to 2022 under bael cultivation as well as the usage of vegetative propagation techniques become popular among farmers (Anonymous, 2023). All this leads to create higher demand for healthy and superior rootstocks. To accomplish the increasing demand for superior rootstock, the bael seedlings needs to be grown from seeds, but its seeds cannot germinate easily and took long period because of seed dormancy due to hard seed coat, physiological immaturity of the embryo, impermeability to water and gases and excess of certain endogenous growth inhibitor (Chattopadhyay and Mahanta, 1989). Additionally, bael seeds are recalcitrant in nature, they lose viability, when stored for a long period of time. For farmers, poor germination is a serious obstacle for producing adequate quantity of rootstock with buddable size in short time span. To improve germination, seed priming is employed for breaking dormancy. In seed priming, seeds are soaked in a bioactive chemical to initiate the embryo's pre-germinative metabolism. Primed seed emerges earlier from soil and produces more uniform seedlings than untreated seed. Various seed priming methods employed for breaking dormancy are hot water soaking, scarification, bio-fertilizers treatment and chemical treatments. Growth regulators like NAA and GA_3 also improve seed germination, seedling growth and survival by increasing the supply of reserved mineral elements, water uptake and altering membrane permeability. GA_3 also used to weaken the seed coat, making it easier for the radical of seedling to penetrate. Biofertilizers contains microorganisms which helps in transforming inert nutrients to useable nutrients via biological processes (Athani and Revanappa, 2009). Pre-sowing treatment with chemicals like KNO_3, KH_2PO_4 and plant growth regulators such as NAA and GA_3 and of micronutrient combination increased germination and subsequent seedling vigour in many fruit crops (Ratan and Reddy, 2003). The influence of seed priming treatments is abysmally understood in bael. The primary motive of the researcher to conduct this investigation, was to work out the best seed priming treatment in terms of concentration as well as duration to improve germination percentage and achieve the buddable seedling as early as possible and reduce the germination time for better seedling establishment of bael.

Material and Methods

The study was carried out during 2020-21 at Microbiology laboratory of Regional Research Station, Bawal, CCS Haryana Agricultural University. For seed extraction, completely matured, healthy, and disease-free bael fruits were collected from orchard of Regional Research Station, Bawal. Dead, immature and non-viable seeds floated on saline in water were eliminated. The extracted viable seeds were rinsed with tap water. After washing, the seeds were kept in shade for drying. The healthy bael seeds (225 per treatment) were exposed to various chemicals and bio - inoculants of varying concentrations and duration based on various researcher's findings on different crops. The treatments consist of GA_3 @ 50 and 100 ppm for duration of 24 hours, NAA @ 50 and 100 ppm for 24 hours, IBA @ 50 and 100 ppm for 24 hours, KNO_3 @ 1.0% for 24 hours, *Azotobacter* (HT 54) for 30 minutes, *Trichoderma viride* for 30 minutes, *Rhizobium* (CK 16) for 30 minutes, PSB (P 36) for 30 minutes, Hot water treatment for 30 minutes, Conc. Nitric acid (98%) for 3 minutes, Conc. Sulphuric acid (98%) for 3 minutes and control. Observations were recorded for germination percentage, mean germination time, dry weight of seedling, seedling length and vigour index. For calculating germination percentage, treated bael seeds were planted in one per cent agar solution at a temperature of 28ºC in a seed germinator (Caltan-NSW-192) (Fig 1). After 20 days of sowing the final count of normal seedling was done and per cent germination was calculated on basis of total seeds sown as per the guidelines of International Seed Testing Association (ISTA, 2010).

$$\text{Germination per cent (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100$$

The duration of germination (in days) was recorded from the date of sowing of seeds to the date of germination of last seed in a treatment. For measuring seedling length (cm), ten normal seedlings were chosen randomly per treatment and length was measured with the help of meter rod from tip of root to the tip of shoot. Five seedlings selected from every treatment for measuring dry weight. Dry weight of individual seedlings was measured with digital electronic balance (A&D weighing- Galaxy HR-150AZ). The seedlings were kept at 60 ± 2ºC in hot air oven for drying, until a constant weight achieved. Formula proposed by Abdul-Baki and Anderson (1973) was used for calculating vigour index I and II.

Vigour Index I = Standard germination (%) × Average seedling length (cm)

Vigour Index II = Standard germination (%) × Average seedling dry weight (mg)

The data collected throughout the investigation was statistically evaluated using Fishers (1958) analysis of variance (ANOVA) technique. The mean value of different parameters was compared using critical difference. The statistical software OPSTAT was used to carry out the entire statistical analysis.

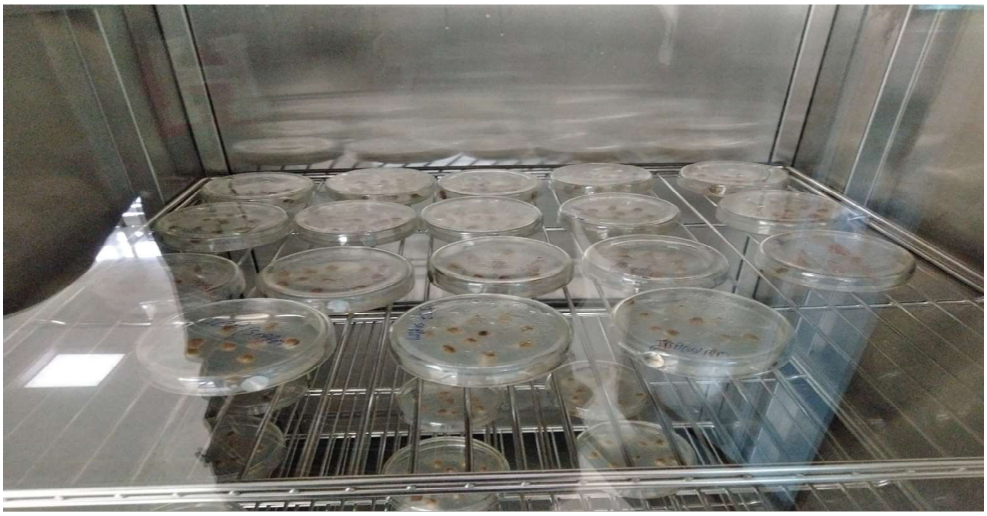

Fig. 1: Photo showing seeds in seed germinator at 28°C

Results and Discussion

Germination percentage

The seed priming treatments significantly influenced the germination percentage of bael (Table 1). Germination per cent ranged from 63.3 to 83.3 per cent. Seeds treated with GA_3 @ 100 ppm for a period of 24 hours resulted in highest germination per cent (83.3 %) while the lowest germination per cent (63.3%) was observed in control. The findings showed that bael seeds are physically dormant. The enhanced germination observed with GA_3 application may be attributed to the exogenous stimulation of aleurone layers within the seeds. GA_3 aids in the production of α-amylase enzyme, which facilitates the conversion of insoluble sugars into soluble forms. Moreover, GA_3 also acts as a catalyst for initiating radical growth by alleviating certain metabolic impediments. (Kolumbina *et al*., 2006, Babu *et al*., 2010). GA_3 also enhanced the seed germination by alleviating the inhibitory effects exerted by endogenous seed inhibitors (Wareing *et al*., 1968). The results mentioned align with the conclusions of Boricha *et al.* (2020). According to their findings, guava seeds treated with 150 mg/l GA_3 for period of 24 hours resulted in maximum germination percentage (80.77%). Similarly, Joshi *et al.* (2015) revealed that GA_3 has a substantial impact on the germination of acid lime seeds.

Duration of Germination

The results mentioned in Table 1 strongly indicates the significant impact of priming treatments on duration of germination. The duration of germination varied from 12.7 to 18.7 days. Among different priming treatments seeds dipped in sulphuric acid for 3 minutes took lowest duration of germination (12.7 days), that was statistically akin with GA_3 @ 100 ppm for duration of 24 hours (13 days) and KNO_3 @ 1.0 % for 24 hours (13.3 days). However, maximum duration of germination (18.7 days) was observed in control. Early germination with sulphuric acid might be due to the fact that acid softens the rigid coating of seed by dissolving the accumulated lipids and pectic compounds. These compounds are sole responsible for seed hardiness. This softening enhances the permeability of seed coat to gases and water, thereby encouraging early germination (Chattopadhyay and Dey, 1992). Brijwal and Kumar (2014) and Kumar *et al.* (2022) in guava and Sharma (2016) in chironji also reported similar results.

Table 1: Effect of seed priming treatments on germination (%) and duration of germination in bael (*Aegle marmelos* Corr.)

Sr. No.	Treatments	Germination (%)	Duration of germination (days)
1	Control	63.3	18.7
2	IBA @ 100 ppm for 24 hours	76.0	14.3
3	IBA @ 50 ppm for 24 hours	76.0	14.7
4	GA_3 @ 100 ppm for 24 hours	83.3	13.0
5	GA_3 @ 50 ppm for 24 hours	76.0	14.7
6	NAA @ 100 ppm for 24 hours	73.3	14.7
7	NAA @ 50 ppm for 24 hours	73.3	14.7
8	KNO_3 @ 1.0% for 24 hours	80.0	13.3
9	Hot water for 10 minutes	66.0	16.0
10	*Azotobacter* (HT 54) for 30 minutes	70.0	15.7
11	*Trichoderma viride* for 30 minutes	73.3	15.7
12	*Rhizobium* (CK 16) for 30 minutes	80.0	15.3
13	PSB (P 36) for 30 minutes	76.0	15.3
14	Nitric acid (HNO_3) for 3 minutes	70.0	14.0
15	Sulphuric acid (H_2SO_4) for 3 minutes	66.0	12.7
	Range	63.3-83.3	12.7-18.7
CD (p = 0.05)		1.7	1.02

Seedling length (cm)

Data on seedling length varied from 7.5 to 12.2 cm (Table 2). The maximum seedling length (12.2 cm) was observed when seed primmed with 100 ppm GA_3 for 24 hours duration, followed by 50 ppm GA_3 concentration for 24 hours (11.6 cm). Results showed that the minimum seedling length (7.5 cm) was reported in control that was statistically at par with the hot water treatment for 10 minutes. The observed increase in seedling with GA_3 treatment can be attributed to hormones ability to enhance osmotic uptake of nutrients that leads to cell multiplication in the internodal cambium tissue (Krishnamoorthy and Sandooja, 1981). Gibberellic acid plays pivotal role in regulating stem elongation by influencing various cellular processes. It enhances cell wall extensibility by promoting the synthesis of cell wall components and reducing cell wall rigidity. This increased extensibility allows for greater cell expansion and elongation, contributing to overall stem growth. Gibberellic acid also stimulates cell division, leading to an increase number of cells available for elongation. Apart from this, it increases the synthesis of IAA, which has an immediate effect on stem elongation (Leopold and Kriedeman, 1983). Similar observations were reported by Santos *et al.* (2022) in pitahaya.

Dry weight per seedling (mg)

Data in Table 2 illustrates that seeds treated with GA_3 at concentration of 100 ppm for 24 hours resulted in highest dry weight per seedling (153.2 mg), which was statistically at par with KNO_3 at concentration of 1.0 % for 24 hours (151.8 mg) and 100 ppm IBA treatment (151 mg). However, in control, lowest dry weight per seedling (142.0 mg) was noticed. The significant increase in dry weight with GA_3 treatment might be attributed to improved water and nutrient transportation, leading to enhanced photosynthesis and the efficient movement of photosynthates within the seedlings, resulting in greater overall growth and therefore greater dry weight per seedling. Sasikala and Srimathi (2006) observed similar pattern in papaya, whereas, Patel *et al*. (2016) also observed such variations in custard apple.

Table 2: Effect of seed priming treatments on seedling length (cm) and dry weight (mg) per seedling in bael (*Aegle marmelos* Corr.)

Sr. No.	Treatments	Seedling length (cm)	Dry weight/seedling (mg)
1	Control	7.5	142.0
2	IBA @ 100 ppm for 24 hours	10.5	151.0
3	IBA @ 50 ppm for 24 hours	10.1	149.0
4	GA_3 @ 100 ppm for 24 hours	12.2	153.2
5	GA_3 @ 50 ppm for 24 hours	11.6	149.2
6	NAA @ 100 ppm for 24 hours	9.9	149.6
7	NAA @ 50 ppm for 24 hours	9.1	148.0
8	KNO_3 @ 1.0% for 24 hours	11.8	151.8
9	Hot water for 10 minutes	8.2	146.1
10	*Azotobacter* (HT 54) for 30 minutes	9.5	147.6
11	*Trichoderma viride* for 30 minutes	9.7	148.6
12	*Rhizobium* (CK 16) for 30 minutes	9.6	148.0
13	PSB (P 36) for 30 minutes	9.6	149.0
14	Nitric acid (HNO_3) for 3 minutes	9.9	146.6
15	Sulphuric acid (H_2SO_4) for 3 minutes	10.2	148.4
	Range	7.5-12.2	142.0-153.2
CD (p = 0.05)		1.1	2.3

Vigour Index

The highest vigour index I (976) was observed in GA_3 @ 100 ppm seed treatment, closely followed by KNO_3 @ 1.0 per cent. In contrast, control had the lowest vigour index I (448). The value of vigour index I varied from 448 to 976 (Table 3). The value of Vigour index II fluctuates between 8520 and 12256. Maximum vigour index II was noticed in GA_3 @ 100 ppm for duration of 24 hours, followed by KNO_3 @ 1.0% for 24 hours and IBA @ 100 ppm for 24 hours, while, minimum (8520) was noticed in control. In the current study, seeds which are treated with GA_3 @ 100 ppm for 24 hours has higher vigour index I and II by 118.34 and 438.49 per cent, in comparison to control. The increased length and dry weight of seedlings in GA_3 seed treatment may be the potential cause of the rise in vigour indexes. Sheoran *et al.* (2018) noticed that seed soaking with GA_3 resulted in maximum vigour index in ber.

Table 3: Effect of seed priming treatments on vigour index in bael (*Aegle marmelos* Corr.)

Sr. No.	Treatments	Vigour index - I	Vigour index - II
1	Control	448	8520
2	IBA @ 100 ppm for 24 hours	773	11068
3	IBA @ 50 ppm for 24 hours	742	10922
4	GA_3 @ 100 ppm for 24 hours	976	12256
5	GA_3 @ 50 ppm for 24 hours	850	10936
6	NAA @ 100 ppm for 24 hours	694	10472
7	NAA @ 50 ppm for 24 hours	637	10360
8	KNO_3 @ 1.0% for 24 hours	907	11537
9	Hot water for 10 minutes	520	9206
10	*Azotobacter* (HT 54) for 30 minutes	634	9845
11	*Trichoderma viride* for 30 minutes	680	10402
12	*Rhizobium* (CK 16) for 30 minutes	676	10360
13	PSB (P 36) for 30 minutes	706	10922
14	Nitric acid (HNO_3) for 3 minutes	660	9778
15	Sulphuric acid (H_2SO_4) for 3 minutes	646	9394
	Range	448-976	8520-12256
CD (p = 0.05)		52	696

Conclusion

Results of the experiment indicated that minimum time required for germination (12.7 days) was noticed in seed priming treatment with sulphuric acid for 3 minutes, while other parameters such as germination percentage, dry weight per seedling, seedling length and vigour index were recorded maximum in GA_3 treatment at 100 ppm for 24 hours under laboratory conditions. These values highlight the potential of gibberellic acid as an effective treatment to promote seedling growth and overall plant performance.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Effect of *Xanthan gum* seed coating on seed germination and seedling vigour of finger millet (*Eleusine coracana* L.)

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ABSTRACT

Six Hydrophilic polymers *Xanthan* Gum, *Iota Carrageenan*, *Kappa Carrageenan*, *Agar Agar*, Food grade *Agar* and *Gellan Gum* were studied for polymerization potential and water holding capacities. Among the six polymers, *Xanthan gum* and *Iota Carageenan* recorded the maximum values for water holding capacities of 38.27 ml/g and 34.17 ml/g and were forwarded for the Seed coating experiment. Coating experiments consist of twodosages of polymer powders (10g, and 20g /kg) and two concentrations of sticking agent (water 5ml and 10 ml). Coated seeds exposed to seed germination studies against untreated seeds. Results revealed that Finger millet seeds coated with 20 g Xanthan gum + 10 ml water as sticker recorded the maximum values for seed germination (87%), seedling length (26.23cm), dry matter production (12.47mg 10 seedlings^{-1})and Vigour Index I (2282) and II (1084).The % increase over the control was 7 for seed germination, 56 for seedling length (cm), 21 for dry matter production (mg) ,69 for seedling vigour index I and 31for seedling vigour index II. From the studies it could be concluded that Finger millet seeds coated with the *Xanthangum* @20 g can be recommended as pre sowing seed treatment for improving the Seed Germination and seedling vigour.

Introduction

Finger millet (*Eleusine coracana* L.) is one of the important minor millets, extensively cultivated in India with a total area of 2.5 million hectares producing 2.2 million tonnes. It is a rich source for Ca (300-350mg/100g), P(283 mg/100g) and Fe (3.9 g/100g),vitamin B_1, B_2, folic acid and niacin.Millets are adapted to a wide range of Soils.It does not demand rich soils for growth. Nowadays, the area under millet cultivation is continuously declining, that too the crop is majorly cultivated in rainfed /drought prone ecosystems in India. The productivity and profitability of millets cultivation is also affected due to absence of quality seed supply chain and improper crop management. It is a high timeto develop and enhance the productivity of rainfed crops by using the quality seeds and adopting technological interventions to mitigate water stress. Technological intervention to overcome drought stress during seed germination paving way to adequate crop stand could help to increase the productivity and expand millets cultivation in rain fed areas. Hydrophilic polymers has great potential in restoration and reclamation and can hold 400 – 1500 g of water /g (Akther *et al.,*(2004),Mikkelsen*et al.*, (2016)). In ideal situations they can store and provide 95% water for plant absorption (Johnson and Veltkamp, 1985). Blodgett *et.al.,* (1993) found that adding superabsorbent polymers to the soil matrix increased the water holding capacity and also increased the water availability to plants. The superabsorbent polymers also prolonged water availability for plant use when irrigation stopped (Huttermann*et al.,*1999, Abobatta*et al.,* (2018)).

Xanthan gum an excellent hydrophilic polysaccharide, though soil application *Xanthan gum* could improve the soil properties

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(Dehghan *et al.*, 2019 and Soldo *et al.*, 2020). Nevertheless, studies on organic hydrophilic polymers application through seed coating is very scanty or nil. By seed coating the quantity of polymer required can be minimized and also the labour and time required for field application can be reduced. With this background the present study was initiated in Finger Millet.

Material and Methods

Six organic Hydrophilic polymers namely *Xanthan Gum, Iota Carrageenan, Kappa Carrageenan, Agar Agar,* Food grade *Agar* and *Gellan Gum* were collected from the market. The Finger Millet seeds (ATL 1) with 80 % germination and 12 % moisture was used as the base material for the study. The studies were carried out at Agricultural College and Research Institute, Kudumiyanmalai, Pudukkottai, Tamil Nadu during 2022. Organic hydrophilic polymers exposed for polymerization potential and water holding capacities.

Seed coating

The Finger Millet seeds were coated with different dosages of hydrophilic polymer dry powders (*viz.,*10 g and 20 g /kg of seeds) with various dosages of water as sticker (*viz.,* 5ml and 10 ml) and exposed to seed germination studies under lab conditions against the uncoated seeds (Table 1.).

Seed Germination

Germination test in quadruplicate using 25 seeds each with 4 replications was carried out in sand method with 60 % WHC of substrata. Test conditions of 25 ± 2°C and 95 ± 3% RH were maintained in the germination room. At the end of 8 days the number of normal seedlings were counted and the mean expressed as Percentage (ISTA, 2009).

Root length (cm)

Root length of all the normal seedlings from the germination test was measured from collar region to the root tip and the mean expressed in cm.

Shoot length (cm)

Shoot length of all the normal seedlings from the germination test will be measured from collar region to the shoot apex and the mean will be expressed in (cm).

Dry matter production (mg 10 seedlings^{-1})

The seedlings used for growth measurement were shade dried for 24h (after removing the cotyledons) and dried again in a hot Air oven maintained at 85 ± 2^{0}C for 24 h and cooled in a silica gel desiccator for 30 min. The dry weight of seedlings were recorded using an electronic balance and results expressed in mg 10 seedlings^{-1}.

Vigour Index I

Vigour index I values were computed using the following and the mean values were expressed in whole number.

Vigour index I = Germination (%) x total seedling length (cm)

Vigour index II

Vigour index II values were computed using the following formulaand the mean values were expressed in whole number.

Vigour index II = Germination (%) x Dry matter production (g / 10 seedlings)

(Maya *et al.,*2016 reported that).

Table 1. Treatment details

T_0	:	Untreated seeds
T_1	:	10gm Xanthan gum + 5 ml water as sticker / kg of seeds
T_2	:	10gm Xanthan gum + 10ml water as sticker/ kg of seeds
T_3	:	20gm Xanthan gum + 5 ml water as sticker / kg of seeds
T_4	:	20gm Xanthan gum + 10ml water as sticker/ kg of seeds
T_5	:	10gm Iota Carrageenan+ 5 ml water as sticker / kg of seeds
T_6	:	10gmIota Carrageenan+ 10ml water as sticker/ kg of seeds
T_7	:	20gm Iota Carrageenan+ 5 ml water as sticker / kg of seeds
T_8	:	20gmIota Carrageenan+ 10ml water as sticker/ kg of seeds

Results and Discussion

Among the six hydrophilic polymers the polymerization potential and water holding capacities were recorded maximum in *Xanthan gum*38.27 ml/g (3727times) of polymer and in *Iota Carrageenan*34.17ml/g(3317 times) of water absorption than the control ml/g of polymer.The results were in agreement with Mikkelsen (2016), they reported that the hydrolyzedstarch-graft-polyacrylonitrile or H-SPAN polymer can absorb up to 2000 times their weight.*Xanthan gum*and *Iota Carrageenan*were taken for the seed coating experiments. The hydrophilic polymers coating increased the seed germination and seedling vigour of Finger millet. The seeds coated with *Xanthan Gum* (20 g) + Water (10ml) /kg of seeds as sticking agent recorded the maximum values for seed quality parameters. The values recorded were 87%, 26.23cm, 12.47 mg 2282 and 1084 respectively for germination, Seedling length and vigour index I &II. This was followed by the seed coated with *Iota Carrageenan* 20 g + 10ml Water /kg of seeds (85 %, 25.51cm ,11.76mg, 2168 and 999) and control recorded the minimum values of 80%,16.86cm ,10.29mg,1348 and 823 for germination %, Seedling length, dry matter production, Vigour Index I and II. Polymer coatings on seeds provide more efficient imbibitions of water, speed up germination and improved seedling growth. The % Increase over the control in germination was 7%, seedling length 56 % , dry matter production 21% , seedling vigour index I 69% and for seedling vigour index II was 31% (Fig.1 to Fig.3.).

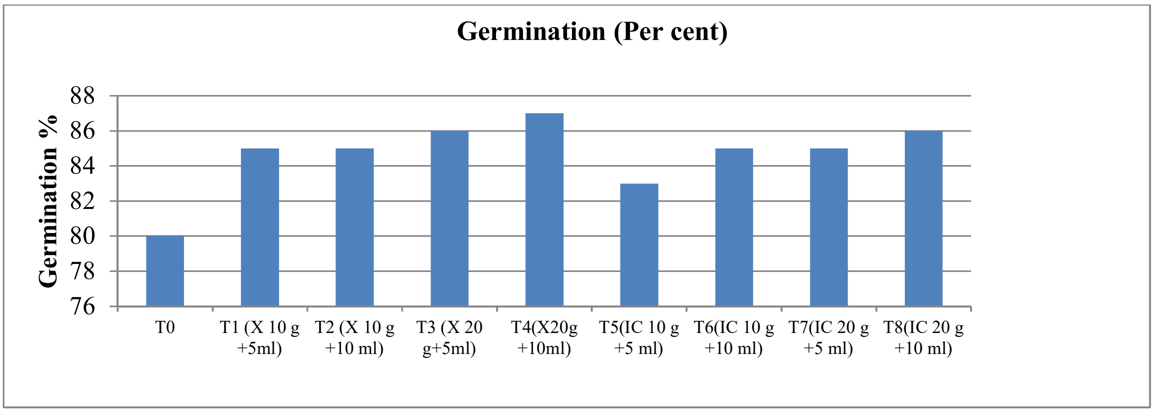

Fig. 1. Effect of Xanthan Gum seed coating on germination % of finger millet

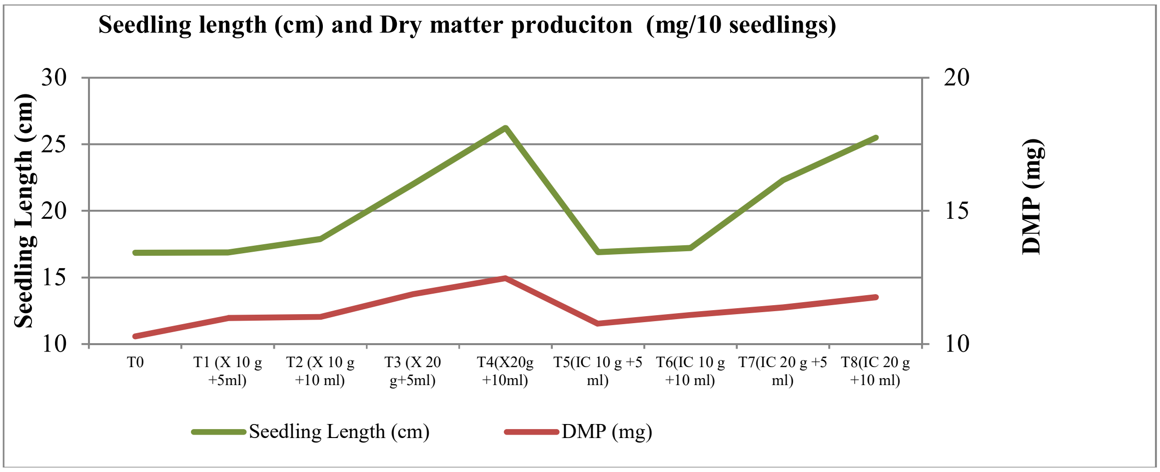

Fig. 2. Effect of HP seed coating on seedling length (cm) and dry matter produciton (mg/10 seedlings) in finger millet

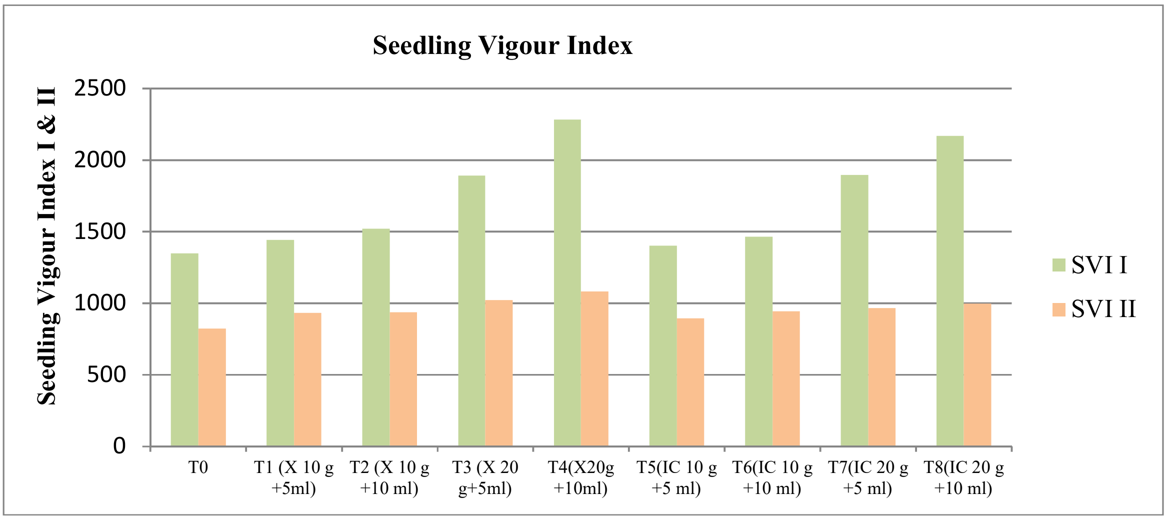

Fig.3. Effect of HP seed coating on seedling vigour index I and II in finger millet

The results were in agreement with Rambod *et al.,* (2018), Chang *et al.,* (2018) Salachna *et al.,* (2021) they reported that there was a positive correlation observed between seed coating with hydrophilic compounds and seed germination in various crops. The seeds coated with hydrophilic polymers could accelerates the seed imbibitions rate, reducing the time required for full germination, since, the colloidal nature of the hydrophilic polymers seed coating provides a large surface area for water absorption. *Maya Hotta et al.,*(2016) they reported that Super Absorbent Polymer coatings on seeds provide more efficient imbibitions of water,speed up germination and improved seedling growth. *Xanthan gum* an excellent organic hydrophilic polymer it could hold (3727times water) and it is suitable for the preparation of SAP (Super Absorbent Polymer). Coating Finger millet seeds with *Xanthan gum* an organic hydrophilic polymer is a promising technique for maintaining a high water potential in rainfed ecosystems.

Conclusion

Xanthan gum an excellent organic hydrophilic polymer can hold (3727times water) and it is suitable for the preparation of SAP (Super Absorbent Polymer) and can be recommended as a pre sowing seed coating technique for mitigating water stress. From the studies it could be concluded that Finger millet seeds coated with Xanthan gum @ 20 g per kg is a promising technique for maintaining a high water potential in rainfed ecosystems.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Indigenous livestock care practices in Kamlah, Mandi District, Himachal Pradesh: A preserving heritage

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ABSTRACT

Cattle production has been an important source of livelihood for the rural communities. Current study aimed to documenting the indigenous traditional knowledge and practices related to livestock health care system among the people of Kamlah region of Sandhol tehsil of district Mandi (Himachal Pradesh). Reconnaissance surveys were conducted in this region from 2021 to 2022. A total of 65 informants (35 males & 30 females) were interviewed. Ethnoveterinary data was collected through semi-structured interviews and group discussions with elderly people, women, farmers and local herbal healers. In this study, 28 plant species belonging to 23 families were identified; in which herb (57%) were the maximum used life forms and leaves (43%) were the commonly used plant parts. The highest number of species recorded in families were Asparagaceae and Fabaceae (3 species each). A wide range of diseases or disorders of cattle such as bone fracture, eye infection, fever, heat stroke, insect bite, prolapsed uterus, skin disorders and stomach disorders are treated by the people of study area with the help of indigenous medicinal plants. The data was analysed using three ethnobotanical indices i.e., use value (UV), fidelity level (FL) and informant consensus factor (ICF). According to quantitative analysis, plant species with high UV values for curing live stock were *Mentha spicata* L. (0.92), *Cassia fistula* L. (0.77) and *Stephania rotunda* Lour. (0.77). FL% values ranged from 25 to 100% and ICF values ranged between 0.97 to 1.00. These findings were at primary level and provide basic information to the researchers for carrying out phytochemical and pharmacological investigations, to create more effective veterinary drugs.

Introduction

Nature harbours a wide range of biodiversity. Medicinal plants play an important role in biodiversity conservation and research (Kumari *et al.,*2022). Since the time of civilization, medicinal plants have been widely used to cure human as well as animal diseases (Thakur *et al.,*2021). A great proportion of people in developing countries like India, are majorly rely on medicinal plants for their ethnoveterinary practices especially in rural areas. Ethnoveterinary practices is a branch of science, that is based on folk belief, traditional knowledge, methods, skills, procedures and practices used for curing diseases and maintaining animal health (Tabuti*et al.,* 2003). Livestock is considered as one of the important sources of livelihood mainly in mountainous and high elevation areas. Here people depend on cattle for food, local economies, social security and cattle strength, which represents a symbol of stature (Moyo and Swanepoel, 2010; Abbasi *et al.,* 2013). Plants are great source to create wide range of modern drugs for the treatment of livestock diseases. Medicinal plants have various secondary metabolites which are biologically active compounds (Prakash *et al.,* 2021). Ethnoveterinary practices have attained significance over the years due to their low side effects. Indigenous

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ethnobotanical knowledge has been passed down from one generation to other orally. Currently such indigenous knowledge is held by the older people of community due to rapid migration of younger generation to the cities for various purposes. This cause loss of traditional knowledge among them. The people of Himachal, one of the largest states of Western Himalayan region in India, rely primarily on traditional ethnoveterinary expertise to treat livestock diseases. Various ethnoveterinary studies have been carried in Himachal Pradesh (Singh & kaushal, 2000; Singh & Misri, 2006; Sehgal & Sood, 2013; Shrivastava *et al.,* 2017; Kumar & Chander, 2018; Prakash *et al.,* 2021; Bishist *et al.,* 2022). However, ethnoveterinary plant of Kamlah region of Sandhol Tehsil of mandi district of Himachal Pradesh has not explored. The aim of our study is to conduct ethnoveterinary surveys in unexplored regions to document the ethnoveterinary knowledge.

Material and Methods

Study Area

The study was carried out in Kamlah region of Sandhol tehsil of Mandi district. Kamlah is a rural area in Sandhol tehsil inhabited by religious and spiritual community. In the17th century, the famous Kamlah fort was built by Raja Suraj Sen of Mandi in this area.

Methodology

To collect the indigenous ethnoveterinary information from the study site field surveys were done in March 2021 – April 2022 by visiting ethnic communities in Sandhol tehsil. As per questionnaire, information was gathered through group discussions and semi-structured interviews adapted from Jain and Goel (1995) with local people about the indigenous applications of plant. A total of 65 informants (35 males and 30 females) of different age group (21-80 years) were interviewed. The residents of the study area played an important role in the collection and local identification of plant species. The ethnoveterinary significance of the collected plant species contains the information about their vernacular names, part/s used to treat various ailments, method of drug preparation and mode of administration. All collected plants were dried, pressed, preserved and mounted on herbarium sheets by using method adapted from Singh and Subramaniam (2008).

Data analysis

The information or data collected by interviewing the locals and traditional healers was analysed by different quantitative indices such as use value (UV), fidelity level (FL %) and informant consensus factor (FIC).

Use Value Index:

Use value indices were calculated by using the quantitative method adapted by Leonti (2022). It is used to evaluate the relative importance of plant species known to the informants. The use-value calculated as:

$$UV = \frac{\sum U}{N}$$

In the above equation, U is the number of usage reports cited by each informant for a specific plant species, and N is the total number of informants selected for interview. High UV value describes many use-reports for a plant implying its importance to the locals. Low UV describes few reports related to its use and plant is not much important.

Fidelity Level

This method is used to identify the most preferred species among many plant species used to cure specific ailments (Leonti, 2022).

$$FL\% = \frac{Np}{N} \times 100$$

In the following equation, Np is the number of use reports cited for a given species for the treatment of a particular ailments and N is the total number of use reports cited for any given species (Bhatia *et al.,* 2014). If FL value is higher (100%) for plant species, it means that almost all usage reports pertain to the same way of using it, whereas, if a low FL percent value is produced, then that plant might be used for various different purposes or ailments (Musa *et al.,* 2011).

Informant Consensus Factor

Informant consensus factor was calculated using the following formula (Heinrich *et al.,* 1998; Rana *et al.,* 2019)

$$FIC = Nur - Nt/Nur - 1$$

Where Nur refers to the total no. of use reports for each ailment category, Nt refers to the total number of plant species used for that category. This formula was calculated to measure the homogeneity in the ethnomedicinal information documented from the traditional informants.

Results and Discussion

Socio-demographic characteristics

A total of 65 informants are selected and categorised into three groups according to their age. Majority of informants belong to the age group of 41-60 (30), subsequently followed by 61-80 (20) and 21-40 (15) years old (Table 1). The ethnoveterinary data was collected from the study site through open discussion and semi-structured interviews. People of the study area depend largely on traditional plants for maintaining their cattle health. They followed ancient method such as plant-based medication to treat their livestock. Even govt. employees of the area have considerable knowledge regarding the ethnoveterinary practices. Maximum informants (about 70%) have gained information about the medicinal plants from their elder family members (parents & grand-parents) and local herbal healers. It is evident from the study that older informants have diverse traditional ethnoveterinary information in comparison to younger people. Various research found that young generation are not interested in ancient system of treatment (Kapoor, 2017). This indigenous traditional knowledge is at the verge of extinction due to modernization and rapid cultural change (Kubkomawa *et al.,* 2013). Therefore, there is a need to encourage young generation to take interest in ethnoveterinary practices to preserve this knowledge.

Table 1: Demographic details of the informants in the study area

Variables	Category of informants	Number of Informants	Percentage (%)
Gender	Male	35	53.85
	Female	30	46.15
Age group	21-40	15	23.08
	41-60	30	46.15
	61-80	20	30.77
Education level	Illiterate	10	15.39
	1^{st}-5^{th} class	15	23.08
	6^{th}-10^{th} class	23	35.38
	Above 10^{th} class	17	26.15
Occupation	Farmers	25	38.46
	Govt. Employees	15	23.08
	Others	25	38.46

Diversity of recorded ethnoveterinary plants

The data collected from the study site was arranged systematically in tubular form that includes scientific name, local name, family, habit, part/s used, route used, ailment treated and mode of administration (Table 2). Information of 28 plant species used in ethnoveterinary practices collected from 65 informants. These plants are distributed among 23 families, 28 genera and 28 species. Maximum plant species collected were herb (57%) followed by shrubs (21%), tree (18%) and climber (4%) respectively (Fig. 1). Knowledge of the people regarding the application of plants varies greatly from one area to other. In the present study, herbs were the most used life form. Many previous studies shown the similar results in which herbs were the

Table 2: Plant species used to treat different livestock ailments/disorders by the people of Kamlah region of Sandhol tehsil of Mandi district of Himachal Pradesh

Scientific Name	Local Name	Family	Habit	Ailments /Treatment	Part/s Used	Route used	Mode of Administration	UV
Agave cantala (Haw) Roxb. ex Salm-Dyck	Banskora	Asparagaceae	Herb	Worm infection	Leaves	Topical	Leaves extract is directly applied to the worm infected area.	0.46
Ageratum conyzoides L.	Fulnu	Asteraceae	Herb	Wound	Leaves	Topical	After washing the body parts, leaf extract is applied properly on the wound.	0.38
Aloe vera (L.) Burm.f.	Aloe vera, Daware	Asparagaceae	Herb	Appetizer, stomach disorder	Leaves	Oral	Decoction of leaves (200ml) is given to the cattle as appetizer and to treat stomach disorders.	0.54
Arisaema tortuosum (Wall.) Schott	Sarpchllii	Araceae	Herb	Prolapsed uterus	Fruit	Oral	Extract of fruit mixed with fodder is given to cure prolapsed uterus in cattle.	0.26
Asparagus adscendens Roxb.	Sanspaien	Asparagaceae	Shrub	Heat stroke	Root	Oral	Root powder mixed (50g) with fodder is given to treat heatstroke.	0.35
Berberis lycium Royle	Kashmal, Rashonth	Berberidaceae	Shrub	Eye disorder, Fever	Root	Oral, topical	Root extract is poured in eyes of animal to reduce redness and discharge. Decoction of roots is given to treat fever.	0.60
Brassica compestris L.	Saron, Sarson	Brassicaceae	Herb	Constipation, skin disorder	Seed	Oral, topical	1/2 L seed oil is given orally to the animal to treat constipation. Seed oil by adding small amount of salt is applied topically to treat skin infections.	0.69
Carissa spinarum L.	Garne, Garnu	Apocynaceae	Shrub	Heat stroke	Leaves	Topical	Paste of the leaves applied topically to treat heat stroke.	0.37
Cassia fistula L.	Aahli, Amaltas	Fabaceae	Tree	Indigestion, Skin disorder	Fruit	Oral	Decoction of pods (250 ml) mixed with jaggery (50-80 g) fed to the animals to treat indigestion. Pod extract applied topically to treat skin disorders.	0.77
Cannabis sativa L.	Bhang	Cannabaceae	Herb	Insect bite	Leaves	Topical	Leaves extract is applied to the affected area as antidote to insect bite.	0.49

Commelina benghalensis L.	Chura	Commelinaceae	Herb	Milk enhancement	Aerial parts of plant	Oral	Plant is used as fodder to enhances milk production.	0.40
Dodonaea visoca (L.) Jacq.	Mehndu	Sapindaceae	Shrub	Bone fracture	Leaves	Topical	Paste of the leaves of *Dodonaeaviscosa* (250g) and *Cuscutareflexa* (100g) is applied to the affected area to cure bone fracture.	0.51
Dysphania ambrosioides (L.) Mosyakin&Clemants	Keh-Ajawain	Amaranthaceae	Herb	Indigestion, Stomach disorder	Leaves	Oral	Decoction of leaves is used to treat indigestion and other stomach related problems.	0.69
Euphorbia heterophylla L.	Dudli	Euphorbiaceae	Herb	Milk enhancement	Aerial parts of plant	Oral	Aerial parts of the plant along with other fodder is given to the cattle to increase lactation.	0.38
Ficus auriculata Lour.	Triambal	Moraceae	Tree	Milk enhancement	Leaves	Oral	Leaves used as fodder to increase milk production.	0.54
Fumaria indica (Hausskn.) Pugsley	Pithpapra	Papaveraceae	Herb	Milk enhancement	Aerial parts of plant	Oral	Whole aerial parts of the plant are used as fodder to increase milk production.	0.46
Grewia optiva J.R.Drumm. ex Burret	Buel	Malvaceae	Tree	Milk enhancement	Leaves	Oral	Leaves mixed with other fodder to enhance milk production.	0.49
Hordeum vulgare L.	Jau	Poaceae	Herb	Milk enhancement	Seed	Oral	Crushed seed (150-250 g) is given with feed for 15-20 days to increase lactation.	0.31
Mentha spicata L.	Pundina	Lamiaceae	Herb	Fever, Indigestion, Heat stroke	Leaves	Oral	Decoction of leaves of Mentha (50g), Onion (30g) and Guava (40g) is given to the cattle to treat fever, indigestion and heat stroke.	0.92
Murraya Koenigii (L.) Spreng.	Gandhla, Gandelu	Rutaceae	Shrub	Milk enhancement, Stomach disorder	Leaves	Oral	Leaves cooked in lassi (1-2 L) fed to the cattle to enhance milk production and treat stomach disorders.	0.73
Oroxylum indicum (L.) Benth. ex Kurz	Arlu	Bignoniaceae	Tree	Indigestion, Constipation	Fruit	Oral	Decoction of uniped fruit (200g) is given to the cattle to treat indigestion and constipation.	0.66
Phyllanthus emblica L.	Ambla, Amla	Phyllanthaceae	Tree	Indigestion, Constipation	Fruit	Oral	Mixed fruit powder (equal amount) of *Phyllantus emblica*, *Terminalia*	0.54

							bellerica, *Terminalia chebula are* given orally in empty stomach for indigestion and constipation.	
Rumax hastatus D. Don	Ambi	Polygonaceae	Herb	Skin disorder, Wound	Aerial parts of plant	Topical	Paste of aerial parts (300g) is applied directly on the wound and infected skin.	0.69
Stephania rotunda Lour.	Bis-Khappar	Menispermaceae	Climber	Flatulence, Mastitis	Tuber	Oral, Topical	Small piece of tuber cooked with fodder is given to the cattle to treat flatulence. Paste of tuber (100g) is applied on the infected area to cure mastitis.	0.77
Trifolium alexandrinum L.	Barseem	Fabaceae	Herb	Milk enhancement	Aerial parts of plant	Oral	Aerial parts of the plant are used as fodder to increase lactation.	0.40
Trigonella foenum-graecum L.	Methi, Mirthe	Fabaceae	Herb	Bloating	Seed	Oral	Soaked seed mixed with fodder is given to cattle to treat bloating.	0.34
Verbascum thapsus L.	Bantambaku	Scrophulariaceae	Herb	Indigestion	Fruit	Oral	Concoction of fruit of *Verbascum Thapsus* (80g), *cassia fistula* (50g) and leaves of *Allium cepa* (30g) is given to the cattle to treat indigestion.	0.46
Zanthoxylum armatum DC.	Tirmir	Rutaceae	Shrub	Fever and digestion.	Leaves	Oral	Thick tablets made from paste of leaves of *Zanthoxylum armatum, Allium cepa* and *Centella asiatica* by adding jaggery and 2-3 chillies are given orally once in a day to the cattle to treat fever and digestion.	0.55

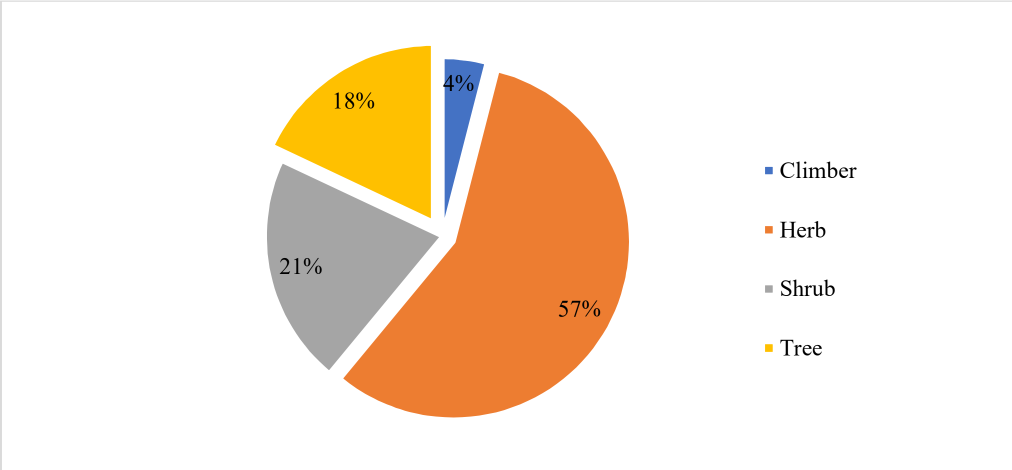

Figure 1: Pie chart showing life forms present in the study area

most commonly used life form (Sharma *et al.,* 2022; Singh *et al.,* 2022) while in some studies trees were the extensively used life form (Musa *et al.,* 2011). These plants belonged to family Amaranthaceae, Apocynaceae, Araceae (1 species each), Asparagaceae (3 species), Asteraceae, Berberidaceae, Bignoniaceae, Cannabaceae, Commelinaceae, Euphorbiaceae (1 species each), Fabaceae (3 species), Lamiaceae, Malvaceae, Menispermaceae, Moraceae, Papaveraceae, Phyllanthaceae, Poaceae, Polygonanceae (1 species each), Rutaceae (2 species), Sapindaceae, Scrophulariaceae (1 species each) (Fig. 2). among 23 families, Asparagaceae and Fabaceae (3 species each) documented with maximum number of plant species. It is evident from the comparison of current study with the previous, that plants and their parts can be used in more than one way to treat various ailments in different regions. Exact dosage of many herbal formulations is not known. Among the plant parts, leaves (43%) were found to be extensively used for the treatment of majority of diseases followed by aerial parts (18%), fruit (18%), seed (11%), root (7%) and tuber (3%) (Fig. 3).

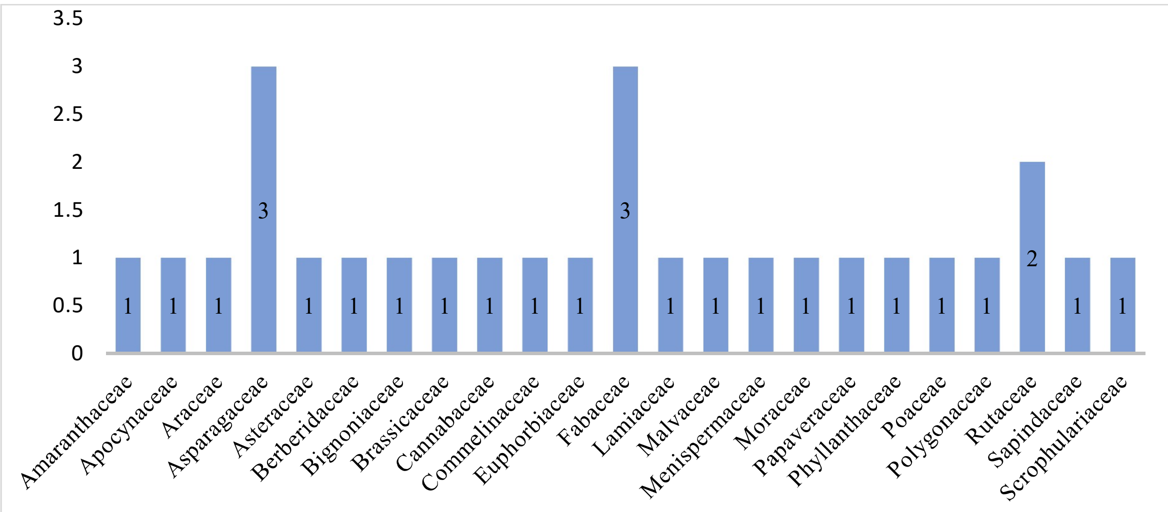

Figure 2: Graph showing the number of plant species belonging to their families

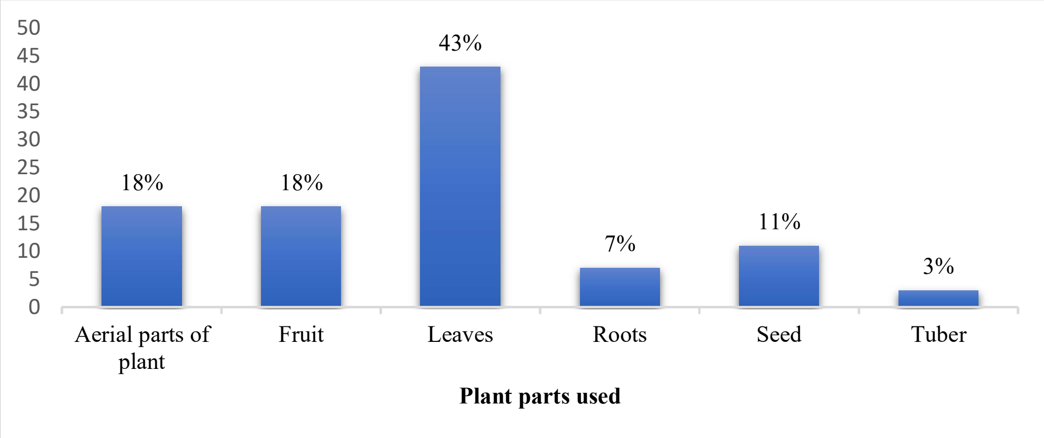

Figure 3: Showing the plant parts used in the treatment of livestock

So study reveals that herbs were the most used life forms (57%) and leaves were the frequently used plant parts (43%) for the ethno-veterinary practices. Previous researches have also documented leaves as most commonly used plant part (Prakash *et al.,* 2021; Thakur *et al.,* 2021). The present study reported using the leaves of *cannabis sativa* to treat insect bite. A previous study from Poonch district (J&k) reported the use of leaves of *cannabis sativa* to treat body pain and intestinal worms (Dutta *et al.,* 2021). Leaves of *Grewia optiva* was used as galactagogue in the study area. In contrast, crushed bark of the *G. optiva* was used to cure worm infection by the residents of Hamirpur district (Kumar & Chander, 2018). Leaves of *Murraya koenigii* were used for milk enhancement and to cure stomach disorders. Previous study reported that leaves of *M. koenigii* were used to treat dysentery (Thakur *et al.,* 2021). According to the informants of study area, root extract of *Berberis lycium* was used to cure eye infection and decoction of root is given to treat fever. In Doda district of J&K, root decoction of *B. lycium* was used to treat jaundice in cattle (Khateeb *et al.,* 2015). Paste of aerial parts of *Rumex hastatus* was given to cure wounds and infected skin in the study area, while people of Kaghan valley of Pakistan used the paste of young plant to treat cough and flu in the cattle (Shoaib *et al.,* 2021). These herbal medications successfully cure common diseases. Current investigation found 28 plant species used orally and topically to cure livestock. Table 2 described the plant species used to treat the various diseases among cattle during various field surveys. In the study area, different ailments like bone fracture, gastrointestinal disorders, insect bite, prolapsed uterus, skin disorders, worm infection etc. are treated by using traditional medicines. Maximum plant species (13) were utilized to treat gastrointestinal problems, which depict that such incidents are comparatively high in the study area. Similar results to treat gastrointestinal disease with maximum number of plant species have been reported previously (Khateeb *et al.,* 2015; Shoaib *et al.,* 2020; Singh *et al.,* 2022). Medicinal plants help in the prevention and treatment of various diseases, due to the presence of some active metabolites (Rau, 1974; Kumar *et al.,* 2021, Mekhemar *et al.,* 2021; Radha *et al.,* 2021). In current study, according to quantitative analysis, use value (UV) of each species was calculated and ranged from 0.26 to 0.92. The most important species with high UV values were *Mentha spicata* L. (0.92), *Cassia fistula* L. (0.77), *Stephania rotunda* Lour. (0.77), *Murraya koenigii* (L.) Spreng. (0.73) etc. Plant species with low UV values were *Arisaema tortuosum* (Wall.) Schott (0.26), *Asparagus adscendens* Roxb. (0.35) and *Carissa spinarum* L. (0.37). Plants with lowest use value may indicates limited traditional knowledge among the community about them or less distribution of species in the area by some environmental issues (Chaudhary *et al.* 2006, Parthiban *et al.,* 2016). The Fidelity Level **(**FL%) values in this study varied from 25 to 100%. Plant species with 100% Fidelity level indicated that, the plant treated in similar way by the informants. *Agave cantala*, *Ageratum conyzoides*, *Arisaema tortuosum*, *Carissa spinarum*, *Commelina benghalensis*, *Dodonaean visoca*, *Euphorbia heterophylla*, *Ficus auriculata*, *Fumaria indica*, *Grewia optiva*, *Hordeum vulgare*, *Trifolium alexandrinum*, *Trigonella foenum-graecum*, *Verbascum thapsus* were the most preferred plants with 100% FL percent values (Table 3).

Table 3: FL% of plant species used for curing different ailments and disorders

Plant Species	Ailments/ Disorders	Citations	FL%
A. cantala	Worm infection	30	100
A. conyzoides	Wound	25	100
A. vera	Appetizer	15	42.86
	Stomach disorder	20	57.14
A. tortuosum	Prolapsed uterus	17	100
A. adscendens	Heatstroke	23	100
B. lycium	Eye disorder	24	61.54
	Fever	15	38.46
B. campestris	Constipation	30	66.67
	Skin disorder	15	33.33
C. spinarum	Heat stroke	24	100
C. fistula	Indigestion	35	70
	Skin disorder	15	30
C. sativa	Insect bite	32	100
C. benghalensis	Milk enhancement	26	100
D. visoca	Bone fracture	33	100
D. ambrosioides	Indigestion	20	44.44
	Stomach disorder	24	55.56
E. heterophylla	Milk enhancement	25	100
F. auriculata	Milk enhancement	35	100
F. indica	Milk enhancement	30	100
G. optiva	Milk enhancement	32	100
H. vulgare	Milk enhancement	20	100
M. spicata	Fever	20	33.33
	Heat Stroke	25	41.67
	Indigestion	15	25
M. koenigii	Milk enhancement	28	58.33
	Stomach disorder	20	41.67
O. indicum	Constipation	15	34.88
	Indigestion	20	57.14
P. emblica	Constipation	15	42.86
	Indigestion	20	57.14
R. hastatus	Skin disorder	20	44.44
	Wound	25	55.56
S. rotunda	Flatulence	20	40
	Mastitis	30	60
T. alexandrinum	Milk enhancement	26	100
T. foenum-graecum	Bloating	22	100
V. Thapsus	Indigestion	30	100
Z. armatum	Fever	15	41.67

For calculating, Informant Consensus Factor**,** all ailments were grouped into 7 categories on the basis of information provided by the informants (Table 4). In current study, value of ICF ranged from 0.97 to 1.00. Maximum plant species (13) were used to treat gastrointestinal disorders followed by galactagogue (8), dermatological disorders (7), fever (4), bone fracture (1), ophthalmic (1) and reproductive (1) (Table 4). The plant species used to cure gastrointestinal disorders in the livestock includes *Aloe vera*, *Brassica campestris*, *Cassia fistula*, *Dysphania ambrosioides*, *Mentha spicata*, *Murrayakoenigii*, *Oroxylum indicum*, *Phyllanthus emblica*, *Stephania rotunda*, *Trigonella foenum-graecum*, *Verbascum Thapsus*, *Zanthoxylum armatum.*

Table 4: ICF values of different plant species used for curing various categories of ailments & disorders

Ailment/Disorder categories	Nt	Nur	Nur-Nt	Nur-1	FIC
Bone fracture	1	33	32	32	1.00
Dermatological (insect bite, mastitis, skin disorders, wound, wound infection)	7	192	185	191	0.97
Fever (fever, heat stroke)	4	99	95	98	0.97
Galactagogue	8	222	214	221	0.97
Gastrointestinal (bloating, constipation, flatulence, indigestion, loss of appetite, stomach disorder)	13	351	338	350	0.97
Ophthalmic (eye infection)	1	24	23	23	1.00
Reproductive (prolapsed uterus)	1	17	16	16	1.00

Conclusion

The current study is an initial attempt to document the traditional ethnoveterinary knowledge of local people of Kamlah region. Many people in the study area still believe to treat their livestock with traditional medicines. With rapid cultural change and modernization, traditional knowledge among the society faded gradually. So, there is an immense need to document and conserve this valuable information for sustainability. Moreover, this study provides a base for other researchers to find out the therapeutic potential of important plants.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Impact of traditional community tanks rejuvenation on groundwater recharge and crop productivity in Yadgir district of Kalyan Karnataka Region, India

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ABSTRACT

Yadgir district is identified as most backward ditrict by NITI ayoga on account of their "lowest composite indicators in terms of health and nutrition, education, agriculture, water resources, financial inclusion, skill development and basic infrastructure. Traditional community tanks (TCT's) are classic examples of common pool resources that have been traditionally managed by local communities for irrigating their crops since age old and they are a living example that illustrates the capability of a man-made tank ecosystem evolved in harmony with nature to withstand natural disasters like drought, floods, and cyclones. These tanks not only protect and conserve the environment, but also contribute to livelihood security to rural farmers. These tanks have contributed significantly in agricultural production through supplementary irrigation and are declined recent decades in Yadgir district which is susceptible to drought compared to other district in the states. Such 13 TCT's were rejuvenated for enhancing water storage capacity in the district under *"Jal Samvardhane - District-wide Water Conservation Project" by* Bharatiya Jain Sangh (BJS) In colloboration with Dept. of Agriculture, Yadgir. The study proved that, the average water storage capacity was raised by 24.80 percent in selected rejunuvented TCT's. The average GWL increased for all selected tanks from 1.62 m to 3.81 m during the post-monsoon seasons of 2019 and 2020, respectively, compared to 1.31 metres before tank disiltation in Rabi 2018. Pigeonpea yield was increased by 4.13 percent (6.56 q/ha) to 20.57 percent (7.62 q/ha) with an average of 11.80 percent across all TCTs. Similarly, cotton prices increased by 4.85 percent (7.13 q/ha) to 21.53 percent (7.45 q/ha) throughout the growing season, with an average of 13.44 percent across all TCTs. Tank irrigation development activities have a substantial impact on groundwater recharge, access to groundwater, and in turn on the extension of irrigated water area. Tank irrigation development efforts have been shown to alter crop patterns, increase crop yields, and diversify crops, resulting in increased employment and farm income of small & marginal farmers of the Yadgir district.

Introduction

The total water available from precipitation in the country in a year is about 4,000 cubic km. The availability from surface water and replenishable groundwater is 1,869 cubic km and merely 60% of this can be utilized for advantageous purposes. Consequently, there are just 1,122 cubic km of

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usable water in the entire nation (Jain S K., 2019). The need of protecting and properly managing water resources has increased as Indian farmers struggle with the threat of groundwater depletion, weakening and irregular monsoons in recent years (Chowdhury and Behera, 2018). Traditional Community Tanks (TCTs), which are often built and maintained by villagers, are large reservoirs of water that have historically been used to irrigate more than 100 hectares of crops (Sathiyamoorthy et al., 2023; Reddy *et al.,* 2018). TCTs gather and store monsoonal rainwater in this traditional method of water harvesting, which is then used for drinking and protective irrigation during dry spells (Reddy and Behera, 2009). However, their use for irrigation has significantly decreased over the last few decades. TCTs were utilized to irrigate over 3.6 million hectares (17%) of the total irrigated land in India in 1950–1951, but in 2014–2015, that percentage had fallen to just 1.7 million hectares (2.5%) (Reddy *et al.,* 2018). Tank irrigation has always been given more weight in the southern and eastern regions, then in the west and north (Charles *et al.,* 2021). In reality, compared to other regions, the south had the greatest percentage of tanks in use in the nation, at 35% in 2000–01 (Anantha *et al.,* 2021b). Regionally, the area irrigated by tanks decreased steadily in both the south and the north from 1972 to 2008, with the exception of a small increase in the south from 2003 to 2008 (Anantha *et al.,* 2021a). The dramatic reduction in TCT irrigation over the previous decades was caused by a variety of factors, including institutional neglect, policy changes, population growth, and a shift to groundwater use (Singh *et al.,* 2022). Neglect combined with environmental degradation caused the tanks in drought-prone areas to silt, which lowered their capacity (Garg *et al.,* 2020). Populations were increasing at the same time, but the TCTs, which were only intended to serve a small population, nable to meet the needs of a growing population (Anuradha, 2014). After that, groundwater became more prevalent because to Geen revolution technologies and cheaper electricity (Garg *et al.,* 2020). This has resulted in private water management, while governmental policy has conveniently overlooked the upkeep of TCTs (Reddy *et al.,* 2018). TCTs are now deteriorated due to major reasons such as encroachment, siltation, soaking of supply channels, inadequate maintenance of bunds, lack of soil conservation, increase in tank -bed siltation and unauthorized cultivation. Due to this, well-irrigation gained traction and became the single greatest source of irrigation (Vico *et al.,* 2020). Wells began to dry up due to over-exploitation, and there has recently been a renaissance realizing the significance of these old systems (Everard *et al.,* 2018). However, efforts must be increased because less than 10% of decommissioned tanks have been rehabilitated in the last two decades (IGG 2020). In the face of climate change, a comprehensive water policy that encompasses tank irrigation as well as groundwater and canal irrigation and takes into account the variable quantities of rainfall expected in different regions is required (Garg *et al.,* 2020). This will make it easier to connect tanks to deal with extreme precipitation occurrences and connect tanks to canals to get prepared for dry spells (Brauns *et al.,* 2022). Tank capacity and number must be raised in areas that will receive short bursts of heavy rainfall (Stavi *et al.,* 2020). Natural resource management is the most important step toward sustainable development, and it necessitates a high level of participation from people who benefit directly and indirectly from that resource (Chinnasamy *et al.,* 2015). TCT management may be an useful way to conserve extra runoff generated during high rainfall events while also solving the present water crisis (Reddy *et al.,* 2018). Well irrigation and tank storage are inextricably linked, particularly in places with restricted aquifers and rock stratum 40-50 feet below ground (Singh *et al.,* 2022). TCTs assist recharge groundwater by holding runoff water for longer periods of time (Everard *et al.,* 2018). As a result, well owners are a key stakeholder group in tank systems; their interests collide with those of command area farmers (Malik *et al.,* 2014). In most places, the benefits of groundwater recharge have outweighed the benefits of direct irrigation from tanks (Deora and Nanore, 2019). This is reflected in increasing land values beyond the command area, which is regarded as the most valued benefit farmers obtain from the tanks (Srivastava *et al.,* 2008). This is mostly due to tank capacity drop, which has resulted in a reduction in command area (Reddy *et al.,* 2018). Indeed, groundwater irrigation in TCT commands is more dependable because to good recharge and is also available throughout the crop season (Chowdhury and Behera, 2018). Due to unstable water supply from tanks, most tail end farms rely on groundwater (Manjula, 2017). In Tamil Nadu, a U-shaped association between the number of private wells and tank degradation has been discovered (Bitterman *et al.,* 2016). The relationship between tank irrigation (surface water) and groundwater levels is found to be considerable in all conventional community tanks (Chowdhury and Behera, 2018). Tanks were shown to aid increase recharge by 40 % in Tamil Nadu (Van Meter *et al.,* 2016). It is believed that tank irrigation and well irrigation should be utilized in tandem rather than as alternatives to preserve hydrological balance and manage water resources responsibly in the long run (Pabba *et al.,* 2022). No rehabilitation programme in India has undertaken a full rehabilitation of the systems (Anuradha, 2014). The most comprehensive are those financed by the World Bank, whose works included strengthening earthen bunds, rebuilding completely broken sluices, restoring surplus weirs, rehabilitating supply and drainage channels, repairing canal structures, and selective lining of channels (Deora and Nanore, 2019). The impact assessment of rehabilitation programmes is also restricted to certain activities (IGG 2020). There have been very few research papers that have completely analysed the program's impacts in terms of cost-benefit analysis (Charles *et al.,* 2021). A few studies, however, have undertaken a cost-benefit analysis of a restricted number of tanks (Everard *et al.,* 2018). The improved availability of water, which is crucial for assessing the TCT's effectiveness, has been the subject of the impact research. Better water availability influences: irrigation area, cropping pattern, production rates, livestock, feed, employment, water distribution, and so on (Singh *et al.,* 2022). The NGO tank restoration experiments have also highlighted the livelihood aspects of tank dependent populations (Brauns *et al.,* 2022). However, few researches have evaluated the performance of TCTs in general or in relation to institutional arrangements (Biswas *et al.*, 2017). Though these studies did not analyse the impact of rehabilitation, they do provide insight into the potential impact of tanks when fully operational (Reddy and Behera, 2009). A number of studies have indicated significant improvements in productivity, crop intensity, employment, animal production, and so on; also, the supply of fuel wood has improved in the majority of the study tanks (Malik *et al.,* 2014). Another significant benefit of tank repair is improved groundwater recharge. Both drinking water and irrigation wells in the command area and beyond have benefited from rehabilitation (Anuradha, 2014). The increased recharge benefits landowning households directly while indirectly benefiting the poor and landless through an increase in employment days (Deivalatha, 2011). Water marketplaces have emerged, allowing even the destitute to gain access to water. Improved access to drinking water reduces the drudgery of women and children while also improving their quality of life. Simultaneously, extensive canal lining decreased groundwater recharge. In fact, the use of tank storage for artificial recharge during times of scarcity (using the tank as a percolation pond) is quickly gaining on in Karnataka, where orchards and cash crops are replacing grain crops and agricultural diversification is occurring under well irrigation (Brauns *et al.,* 2022). Lining could create a conflict of interest between well owners and command area farmers. Another significant area of influence and dispute is tank desilting, which is done in most NGO programmes but not in large donor-funded restoration programmes. Aside from increasing the tank's water storage capacity, applying tank silt to farmlands increases land production (Ali *et al.,* 2020). In a tank restoration project in AP, it was discovered that silt application enhances yield by 20 to 40% (Sharma *et al.,* 2015). It also lowered the consumption of chemical fertilizers by 50-60% compared to previous years. Tank desilting and application of tank silt to farm lands on a regular basis is a long-standing practice. Desilting is economically viable in Karnataka if there is a market for silt, according to estimates (Singh *et al.,* 2022). Carrying out desilting efforts has recently become tough, not for economic reasons, but due to a labour scarcity or lack of motivation to engage in such onerous work. Due to transportation costs, there aren't many buyers for silt. TCTs have been used for irrigation and residential purposes in Karnataka from ancient times. Though TCTs were a vital element of the agricultural production system, farmers began exploring groundwater through tube wells due to the lack of surface water in TCTs due to eratic and scattered rainfall between 1980 and 2000 (Brauns *et al.,* 2022). As a result, the majority of TCTs have been left unused and unrepaired by both the farming community and the government sector. Karnataka's Community Based Tank Management Project (KCBTMP) began in 2002 with the goal of rehabilitating 2000 irrigation tanks through community engagement on a trial basis. The Karnataka Government (GoK) established an autonomous agency named the Jala Samvardhane Yojana Sangha (JSYS) to manage the entire task (Reddy *et al.,* 2018). The project consisted of three parts: I creating an enabling environment for sustainable, decentralized tank management systems; ii) empowering community-based organizations to take up development and management operations; and iii) implementing system improvements. The goal is to repair the tanks and turn them over to tank user associations (TUAs). The project is supported by 57 cluster facilitation teams (NGOs). Despite having enormous land and water resources, Yadgir is regarded one of the most backward districts in the state and has been designated as an aspiration district. Agriculture in the area is primarily dependent on rainfall, with an average annual rainfall of 836 mm. The district is the most drought-prone in the state of Karnataka and has endured frequent droughts in recent years, causing considerable suffering to the agriculturally dependent society and increasing the vulnerability of the poor. Despite the fact that the district has 36 lift irrigation schemes and 445 minor irrigation tanks, the net area irrigated to net area seeded ratio is only 14 percent (Umesh Barikara, 2020). Groundwater levels in the district have been substantially reduced as a result of exploitation, natural discharge, and a lack of recharging during the pre-monsoon season. Water scarcity had an impact on home requirements, agriculture, livestock, and the livelihoods of the district farming population. As a result, in order to improve the district's water resources, NITI Ayoga chose Yadgir as one of the aspirational districts for a drought mitigation model under the "Jal Samvardhane-District-Wide Water Conservation Project," which was implemented by Bharatiya Jain Sangh (BJS) in collaboration with the Department of Agriculture, Yadgir, in 13 selected tanks during the first phase (Karnataka). As a result, the current study was done to investigate the impact of tank rejuvenation on water conservation and groundwater recharge, with the following goals in mind:

1. To study the effect of tank disiltation on water use, water storage capacity and groundwater recharge in study area.
2. To study the changes in major crop yield under selected community tank command area.

Material and Methods

Study area

The study on rejuvenation of tanks and its impacts were taken up in the selected villages of Yadgir in Kalyana Karnataka region of Karnataka state under "Jal Samvardhane -District-wide Water Conservation Project" by Bharatiya Jain Sangh (BJS) incolloboration with Dept of Agriculture, Yadgir (Fig.1). In first phase, district administration identified the 13 Traditional Community Tanks (TCT's) of various capacity and dimensions after doing the technical feasibility assessment among 350 tanks of the district for desilting works & simultaneously identified the point on *Nala* for construction of checkdams to stop runoff water. Planting of forest plant species which are suitable location were identified all around the bunds of 13 tanks to strengthen the bunds of selected tanks. The interlinking channel moved excess water from upstream to downstream tanks and final surplus flowed into the Bhima and Krishna rivers.

Rainfall data

The daily rainfall data for study period was collected from the near by meteorologica stations established by Central Ground Water Board & publi Works Department. The daily rainfall is estimated for monthly and annual rainfall and results are presented in Figure 2. The collected rainfall data was used to estimation of runoff, inflow and outflow to TCTs.

Details of selected traditional community tanks (TCT's)

The size of TCT's, volume of earth work incurred and number of farmers benefitted from each tanks is presented Table 1. Water storage capacity of selected tanks was calculated before & after the tank rejuvenation by knowing the volume of earth work incurred at each tank. Data on groundwater levels were measured using sensor-based groundwater level indicator at nearby observation wells. A field survey was conducted with beneficiaries under selected Traditional Community Tanks (TCT's) for collection of data related to major crops, cropping pattern, area under different crops before and after tank rejuvenation and used for calculation.

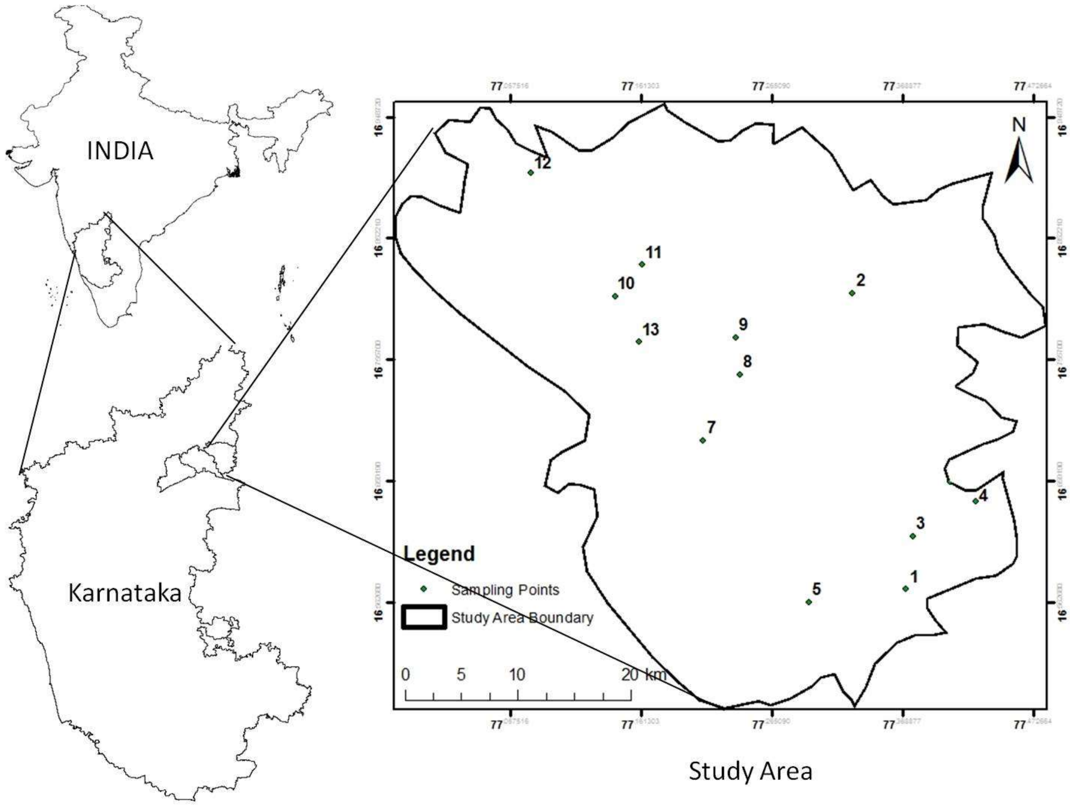
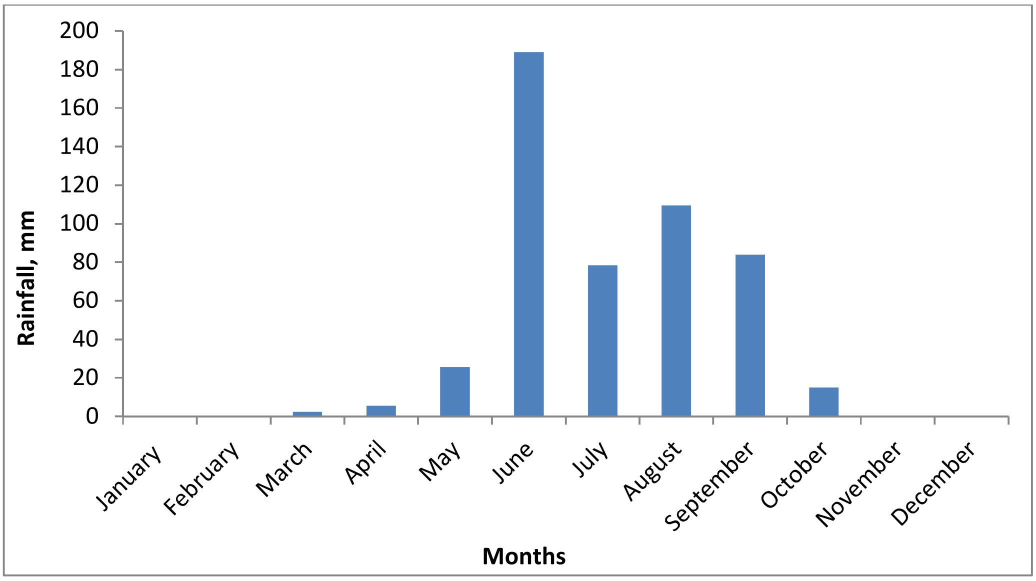
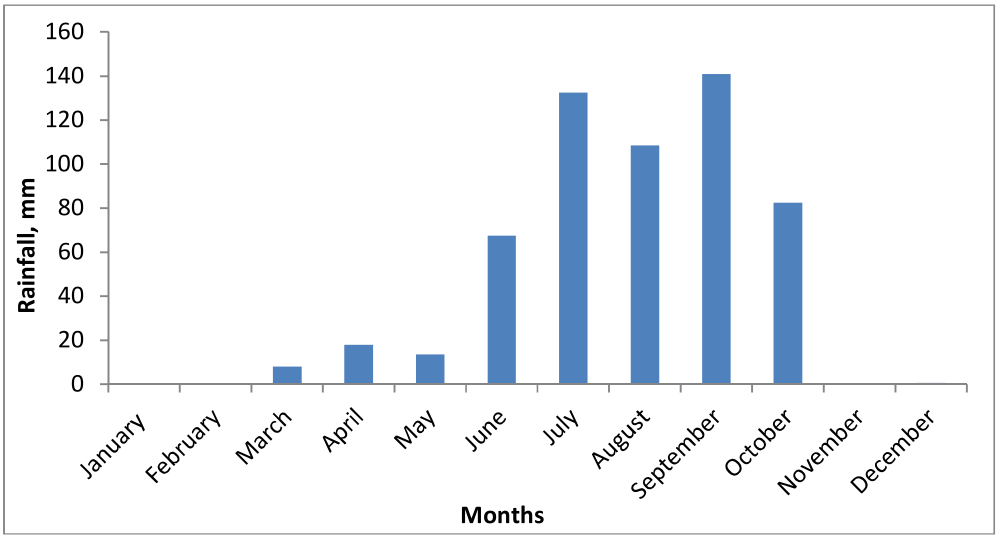


Figure 1: Geographical map of study area



(a)



(b)

Figure 2: Monthly rainfall distribution in study area during 2018 (a) **& 2019** (b)

Table 1: Size of TCT's, volume of earth work incurred and number of farmers benefitted under selected TCT's

Sl.no	Structue Name	As per the Govt scope of work (m^3)	Volume of Excavation (m^3)	Water Storage Created (Ltr)	Beneficiary Farmer
1	Badepalli Tank	48400	62421	62421000	261
2	Chamnalli Tank	13181.82	11	11000	41
3	Jaigram Tank	160000	51888	51888000	149
4	Kandkoor Tank	4009	5350.5	5350500	40
5	Karengi Tank	36131	63912	63912000	144
6	Mailapur Tank	99041	13212	13212000	66
7	Rampur Tank	144000	75852	75852000	155
8	Ramasamudra Tank	80000	50166	50166000	336
9	Wanksambar Tank	55740	50367	50367000	193
10	Yadgir Tank	404000	255252.3	255252300	600
11	Yedhalli Tank	292000	26796	26796000	240
12	Yergol Tank	517120	183939.3	183939300	468
13	Zinkera Tank	88000	110524.5	110524500	488

Results and Discussion

The results of water storage capacity, increase in groundwater levels and increase in crop yield under each selected traditional community tanks are presented & discussed in this section.

Rainfall

The monthly rainfall of study area during 2018 & 2019 is presented in Figure 02 (a & b). Total rainfall of study area was 510 & 572 mm during 2018 & 2019 respectively against average annual rainfall of 836 mm. There was 39 % and 31.57 % less rainfall as compared to average annual rainfall during 2018 & 2019 respectively. However, extreme events during June month in 2018 & September month in 2019 lead to more runoff generation which contributed for increase of water storage capacity of selected community tanks.

Water storage capacity (WSC) of tanks:

Before and after tank rejuvenation, the water storage capacity (MCM) was calculated. All of the desilted anks in the research area had their water storage capacity (WSC) greatly raised. Among all selected tanks, the WSC climbed from 1.45 percent in Zinkara tank (0.02 MCM) to 61.9 percent in Yargola tank (0.13 MCM) (Table 1). Taking into account all decommissioned tanks, the average water storage capacity was raised by 24.80 percent. This rise in WSC results in a significant change in total area irrigated before and after the intervention, ranging from 416 to 1146 ha in *Kharif* and 116 to 340 ha in *Rabi* throughout 2019. During *Kharif and Rabi* 2020, the irrigated command area was raised from 175.88 percent to 193.10 percent. According to the study's findings, tank rejuvenation significantly boosted water storage capacity and irrigated area in the Yadgir district. However, for this study, the area irrigated in the tank command area was compared between two normal monsoon years when the tank was last filled and after desiltation. The rate of increase in water storage capacity was determined by the catchment area's size, rainfall, and cropping pattern (Biswas *et al.,* 2017). Rainfall intensity and duration have a significant impact on runoff created in the catchment region (Vico *et al.,* 2020). However, the Yadgir district's rainfall pattern is unusually scattered and erratic, with only 810 mm of average annual rainfall, which has a direct impact on the water storage capacity of chosen rehabilitated TCTs in the district, and similar results have been recorded by others (Anantha *et al.,* 2021a). Many researchers conducted studies on the effect of tank rejuvenation on the water storage capacity of community tanks across India and reported that rejuvenation of ancient community tanks has a positive impact on the tanks' water storage capacity. According to (Chinnasamy *et al.,* 2015), there was a considerable net increase in water storage and agricultural crop area in Gujarat. Similar findings were obtained for Karnataka by (Brauns *et al.,* 2022) and Tamilnadu by (Van Meter *et al.,* 2016). Well-managed rainwater collection systems by communities or individuals have resulted in considerable improvements in irrigation water supply, the resurrection of the region's agricultural industry, and large gains in farmer incomes and livelihoods (Malik *et al.,* 2014).

Status of groundwater levels (GWL)

Increases in groundwater levels (metres) were estimated for all tanks in the study region before and after tank rejuvenation, and the results are shown in Fig. 3 and Table 2. The findings revealed a considerable increase in groundwater levels in all of the district's restored tanks. After tank rejuvenation in the research region, GWL grew from 0.15 m (Baddepalli) tank to 3.40 m (Yargola) tank during *Rabi* 2019 and 2.10 m (Yadgir, Chamnalli, & Zinkera) tank to 7.05 m (Yargola) tank during *Rabi* 2020. The average GWL increased for all selected tanks from 1.62 m to 3.81 m during the post-monsoon seasons of 2019 and 2020, respectively, compared to 1.31 metres before tank desiltation in *Rabi* 2018. Though GWLs increased during *Rabi* 2019, the percentage gain was insufficient when compared to the desilted tank. The GWL data clearly showed that tank rejuvenation operations had a good influence on groundwater levels in borewells and openwells in selected tank command regions. The difference in groundwater rise between resurrected TCTs was attributed to the amount and availability of stored water in the tanks. No farmer in the command area of these selected tanks had utilised groundwater for irrigation during the *kharif* crop after desilting. Disiltation of TCT's to gather rainwater leads to increased irrigated area and groundwater availability under command area in drought prone regions like Yadgir, and similar findings were experienced by (Van Meter *et al.,* 2016) for Tamil Nadu state. In addition to replenishing groundwater, additional water in the tank caused the water to flow longer distances when the sluice gates opened for irrigation, allowing lower reach farmers to grow (IGG 2020). Across the Indian subcontinent, many researchers observed similar findings. Water levels in wells increased by 2 to 4 feet under the command area of Avalur tank in Tamilnadu (Deivalatha, 2011) and rejuvenated tanks in the Bundelkhand region of Central India reported that, Rejuvenation of the haveli system created an opportunity to harvest surface runoff, which helped to improve groundwater levels in shallow dug wells by 2-5 metres (IGG 2020).

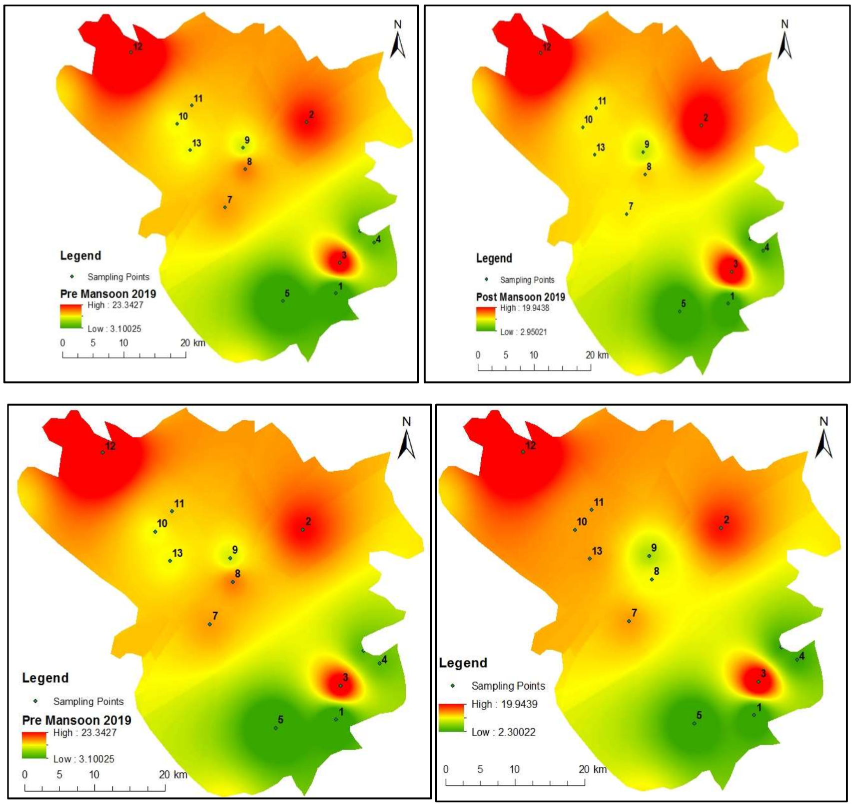


Figure 3: Groundwater levels pre & post monsoon of 2019 and 2020

Table 2: Details of tank area, water storage capacity & benefitted famers under selected traditional community tanks (TCT's) in selected study area

Sl. no	Structure name	Tank Area (ha)	Before Desilting (MCM)	After Desilting (MCM)	Increased WSC (MCM)	% increase WSC
1	Badepalli	121	1.5	1.56	0.06	4.00
2	Chamnalli	12	0.17	0.26	0.09	52.94
3	Jaigram	14	0.11	0.17	0.06	54.55
4	Kandkoor	40	0.56	0.61	0.05	8.93
5	Karengi	10	0.51	0.56	0.05	9.80
6	Mailapur	22	0.33	0.34	0.01	3.03
7	Ramasamudra	36	0.32	0.4	0.08	25.00
8	Rampur	16	0.2	0.31	0.11	55.00
9	Wanksambar	6	0.05	0.06	0.01	20.00
10	Yadgir	130	4.27	4.63	0.36	8.43
11	Yadhalli	20	0.46	0.54	0.08	17.39
12	Yargola	22	0.21	0.34	0.13	61.90
13	Zinkera	101	1.38	1.4	0.02	1.45
	Average	**42.20**	**0.77**	**0.86**	**0.09**	**24.80**

Production and productivity of major crops

The effects of tank disiltation on important crops in the study area before and after tank rejuvenation, as well as the findings are presented in Fig 4-5. Redgram and cotton are the two principal crops grown in Yadgir district during the *Kharif* season; only these crops were studied and assessed. During *Kharif* 2019, Redgram yield increased by 4.13 percent (6.56 q/ha) to 20.57 percent (7.62 q/ha) in Jaigram and Yargola, respectively, with an average of 11.80 percent across all TCTs. Similarly, cotton yields increased by 4.85 percent (7.13 q/ha) to 21.53 percent (7.45 q/ha) in Baddepalli and Yargola with an average of 13.44 percent across all TCTs. The study clearly demonstrated that tank rejuvenation and tank silt application have a positive influence on yield of important crops in selected tank command regions. The application of tank silt and timely supplemental irrigation during the crop growth period increased redgram and cotton yield (Manjula 2017).

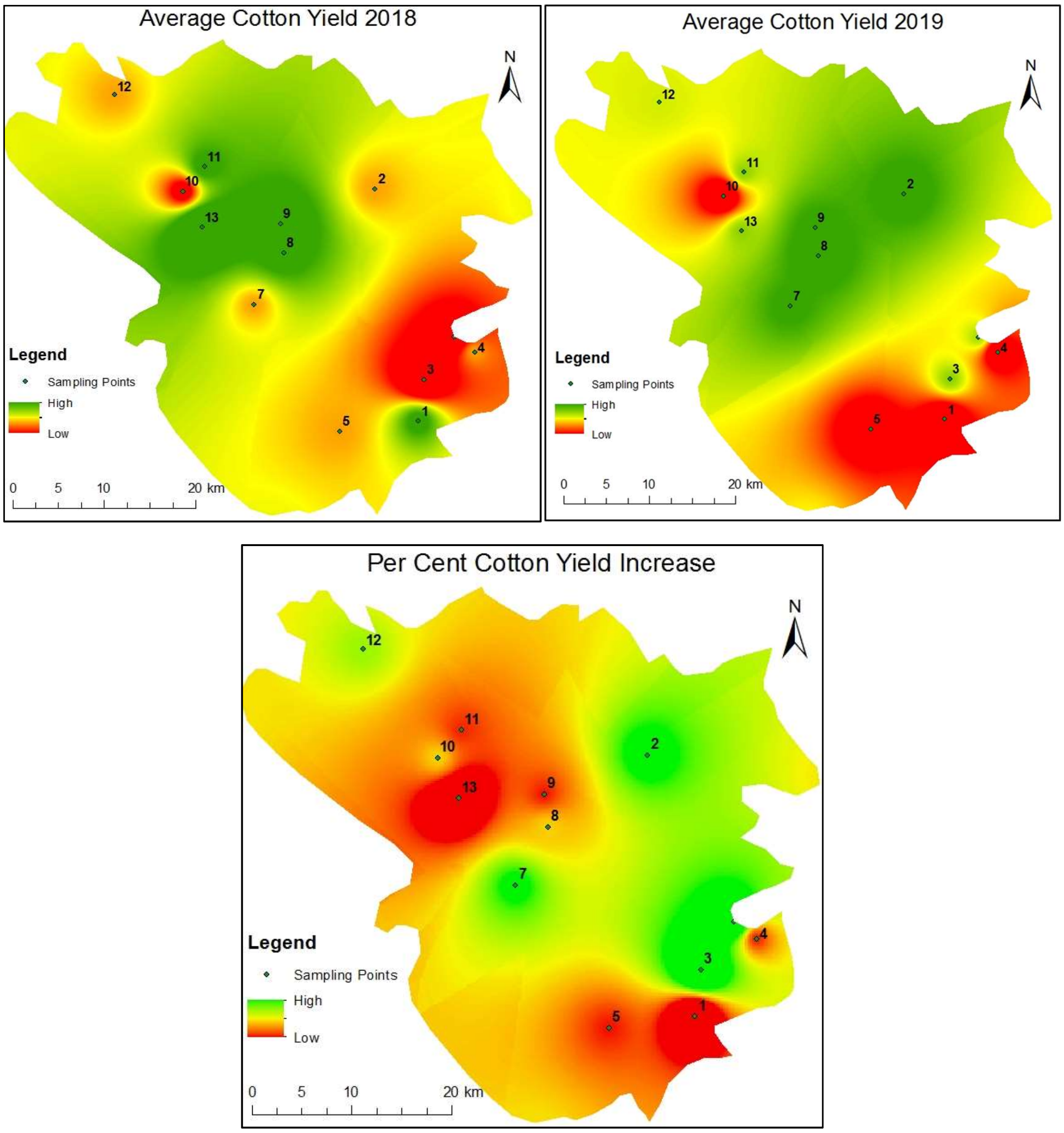


Figure 4: Yield differences in cotton crop after TCT rejuvenation in study area

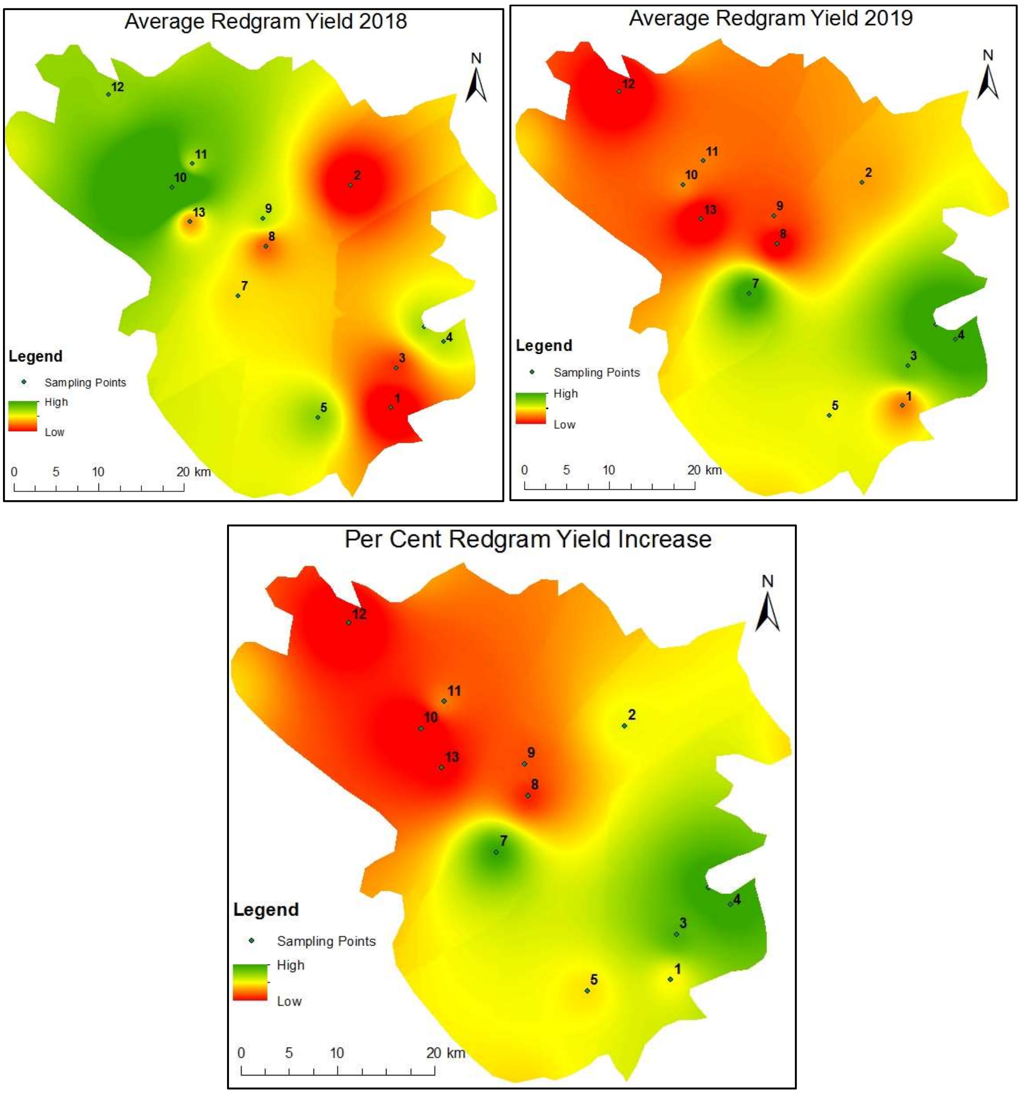


Figure 5: Yield differences in redgram crop after TCT rejuvenation in study area

The combined effect of increased water storage capacity in TCTs and increasing groundwater levels in tube wells within the command area of selected TCTs has made more water accessible for supplemental irrigation, and similar outcomes have been observed by other TCTs (IGG 2020). Supplemental irrigation during crop crucial stages, combined with silt application, increases crop production (Reddy *et al.,* 2020). According to (Srivastava *et al.* 2008), revitalization of community tanks helped to enhance rice yields from 1.92 t ha^{-1} to a range of 2.25 to 3.8 t ha^{-1} in the Keonjhar district of Orissa in eastern India. Many studies concurred that the increased water availability in the community following tank rejuvenation has also permitted irrigation during dry periods, lowering the danger of crop damage during kharif and assisting in crop output increase (Deora and Nanore, 2019).

Conclusion

Because of sustainable agricultural crop production, tank irrigation system management has become the primary intervention for water resource management and rural development. Traditional community tanks irrigation system not only protects and conserves the environment, but also contributes to livelihood security to rural farmers. In the present study, the tank rejunuvation of selected traditional community tanks was helped to improve the livelihood of 50 to 70 % of small and marginal farmers through increasing the crop yield. It is also learnt that, rejunuvated selected TCT's helped to increases the irrigated area and provided water security throughout the crop season and provided opportunities for groundwater recharge, and thus irrigated area extension. The rejunuvated selected TCT's efforts have been shown to alter crop patterns, increase crop yields, and diversify crops, resulting in increased employment and farm income of small & marginal famers of Yadgir district.

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Conflict of interest
The authors declare that they have no conflicts of interest.

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The short-horned grasshoppers (Acrididae and Pyrgomorphidae: Orthoptera) of Karnataka, India: A checklist and distribution data

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ABSTRACT

Short-horned grasshoppers' checklist is presented here. In the present study, the inventory was created using data from a survey conducted in various districts of Karnataka between 2019-2021, including Chikkamagaluru, Dakshina Kannada, Davanagere, Hassan, Kodagu, Shivamogga, Udupi, Uttar Kannada and orthopteran collections at the Insect Systematics Laboratory, Department of Entomology, KSNUAHS, Shivamogga and literature published to date from various parts of Karnataka. A total of 101 species/subspecies belonging to 66 genera, 15 subfamilies and two families i.e., Acrididae and Pyrgomorphidae were reported. Several species were recorded for the first time from the districts investigated, including 9 in Chikkamagaluru, 4 in Dakshina Kannada, 1 each in Hassan and Kodagu, 3 in Shivamogga, 9 in Udupi and 1 in Uttar Kannada. This is the first-ever checklist featuring distribution records for short-horned grasshoppers in Karnataka and is updated with the Orthoptera species file online. The index may help for future taxonomic diversity studies of grasshoppers of Karnataka.

Introduction

Orthoptera is the largest extant polyneopteran order, with more than 29,530 described valid species/subspecies worldwide (Cigliano *et al.,* 2023) and the sixth-largest order of class Insecta (Zhang, 2011). Common names for orthopterans include grasshoppers, locusts, and crickets. Caelifera and Ensifera are the two suborders, that make up this group. The short-horned grasshoppers belong to the suborder Caelifera, are common components of terrestrial insect fauna, and include some of the most voracious pests (locusts), infesting several crops, hence, they constitute an economically significant pest group. Still, pestiferous species are no more than ten per cent, including locusts, that cause extensive damage at times, but not always. Grasshoppers occupy a variety of habitats, and their distribution patterns are changing rapidly due to habitat destruction and anthropogenic disturbances (Fartmann *et al.,* 2021). The short-horned grasshoppers (Acrididae and Pyrgomorphidae) belong to the superfamily Acridoidea and Pyrgomorphoidea, respectively of the superfamily group Acridomorpha. Acrididae and Pyrgomorphidae are two families: Acrididae, the largest and most diverse lineage (Kundu *et al.*, 2020), comprises around 6765 valid species within 28 subfamilies. Pyrgomorphidae, on the other hand, comprises about 149 genera and 488 species within

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two subfamilies worldwide (Cigliano *et al.*, 2023). There are about 1033 species/ subspecies belonging to 400 genera and 21 families of Orthoptera in India. Among them, Acrididae and Pyrgomorphidae include 285 species belonging to 135 genera and 47 species belonging to 21 genera, respectively (Shishodia *et al.*, 2010). Notable workers like Bolivar (1902), Kirby (1914), Uvarov (1921 and 1929), Henry (1940), Dirsh (1954 and 1975), Hollis (1971), Jago (1971), Bhowmik (1985), Shishodia and Mandal (1990), Usmani and Shafee (1985), Ingrisch (1993), Shishodia (1997 and 1999), Kulkarni and Shishodia (2004), Shishodia and Dey (2006), Chandra *et al.* (2007), Mandal *et al.* (2007), Saini and Mehta (2007), Usmani *et al.* (2010), Kumar and Usmani (2012a and 2012b) and Swaminathan *et al.* (2018) have taxonomically studied the group. Karnataka is the largest state in south India and is known for its rich biodiversity (Prajapati, 2010). Nevertheless, little information on orthopteran fauna from Karnataka has been published by Usman and Puttarudraiah (1955), Vastrad (1986), Kumar and Viraktamath (1990 and 1991), Vastrad *et al.* (1991), Mandal *et al.* (2013) and Raghavender and Vastrad (2017a and b). Since then, there have been no detailed faunal and taxonomic studies on grasshoppers from this state, covering the Western Ghats segment. Consequently, it is imperative to explore the grasshopper fauna of Karnataka. There is a need to bring together the scattered information with comprehensive taxonomic data to know the distribution of short-horned grasshoppers in Karnataka.

Material and Methods

Compilation of checklist

No comprehensive checklist for the grasshoppers of Karnataka exists. This paper attempts to generate a checklist and distribution data of Acrididae and Pyrgomorphidae found in Karnataka. The literature published to date by various researchers from Karnataka, collections of orthopteran repository at the Insect Systematics Laboratory, Department of Agricultural Entomology, KNSUAHS, Shivamogga and our current studies were considered for preparing this index.

Sampling and Morphological identification

Grasshoppers of both sexes were collected using a sweep net or by hand from diverse cropping ecosystems in different parts of Karnataka, including Chikkamagaluru, Dakshina Kannada, Davanagire, Hassan, Kodagu, Shivamogga, Udupi, and Uttara Kannada districts during 2019-2021 (Figure-1). Later, specimens were brought to the laboratory, killed using ethyl acetate and pinned as suggested by Richards and Davies (1997). Then appendages and wings were correctly oriented and spread, dried under light for 72 hours and labelled for further taxonomic studies. The Zeiss Stemi 508 stereo zoom microscope was used to examine the labelled specimens and identified up to species level based on the external taxonomic characters by running the key available from the literature. The checklist classification was updated with the Orthoptera Species File Online (Cigliano *et al.*, 2023).

Results and Discussion

As of August 2023, there are approximately 29,530 described species and subspecies within the order Orthoptera worldwide (Cigliano *et al.*, 2023). Of which, 1,033 species/ subspecies of orthopterans have distribution in India (Shishodia *et al.*, 2010). While, Prabhakar and Chandra (2013) listed a total of 159 species belonging to 111 genera of Orthoptera from Karnataka. Of these, the records of short horned grasshoppers still meagre. The family Acrididae comprises 53 species in 37 genera under 12 subfamilies, while Pyrgomorphidae includes nine species in eight genera under two subfamilies. In total, 62 species were listed from the short-horned grasshopper families. In the present study, efforts were made to prepare the grasshoppers checklist and compare distributional records of species in Karnataka through an extensive literature survey and investigations in selected parts of Karnataka. It may aid us in understanding records from new district records that will help future diversity studies. The present checklist comprises a total of 101 species, with 86 species belonging to 56 genera under 13 subfamilies in Acrididae, and 15 species belonging to ten genera under two subfamilies in Pyrgomorphidae. Additionally, this updated checklist includes 39 new species: 33 in Acrididae and 6 in Pyrgomorphidae (Table-1). In the checklist, the family Acrididae constitutes the highest percentage, approximately 85.14 per cent of the total species; while, the family Pyrgomorphidae shares 14.85 per cent (Figure-2).

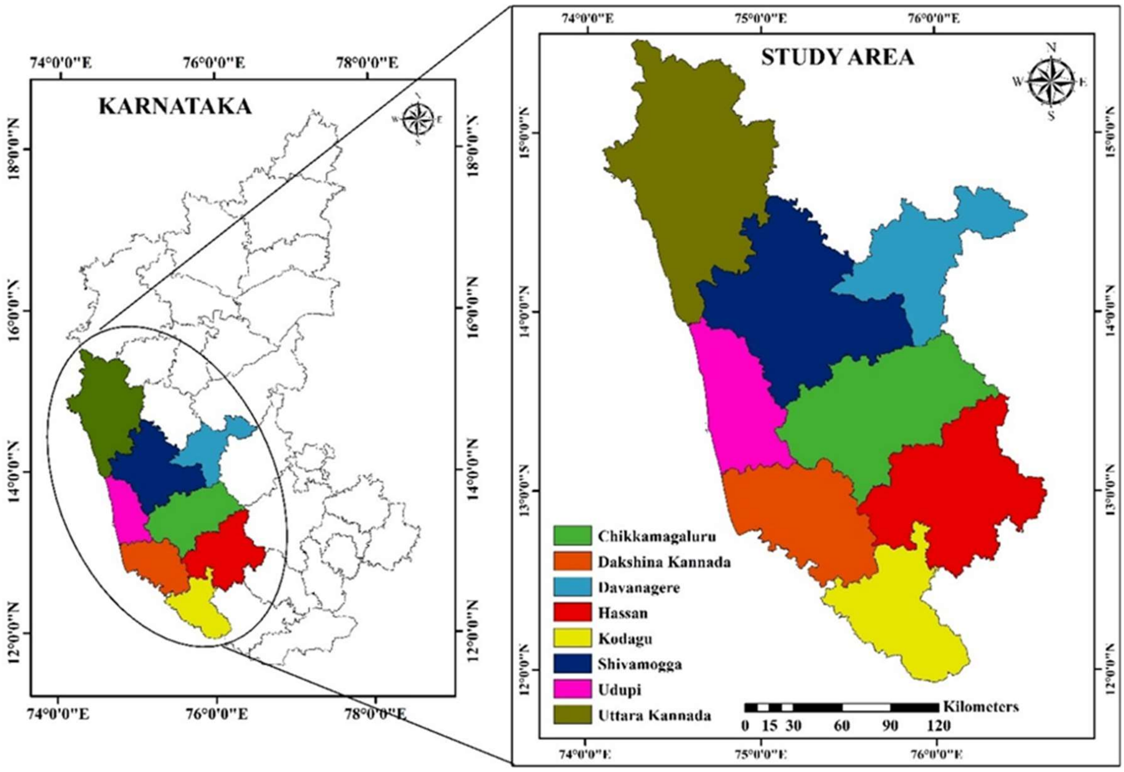

Figure 1: Surveyed districts of Karnataka's are depicted on a map

Table 1: Checklist and distribution records of short-horned grasshoppers in Karnataka

SN	Genus and Species	Type Locality	Distribution in Karnataka
Superfamily Acridoidea MacLeay, 1821 **A. Family Acrididae MacLeay, 1821**			
I. Subfamily Acridinae MacLeay, 1821 (8 genera and 14 species)			
1.	**Genus *Julea* Bolivar, 1914**		
1.	*Julea indica* Bolivar, 1914	India: Karnataka, South Mysore, Goorghalli Estate	Mysore
2.	**Genus *Orthochtha* Karsch, 1891**		
2.	*Orthochtha ramachandrae* Popov, 1914	India: Karnataka, Dhimbam, Biligiriranga hills	Chamarajanagara
3.	**Genus *Pasiphimus* Bolivar, 1914**		
3.	*Pasiphimus sagittaeformis* Bolivar, 1914	India: South Canara District, Nagody	Dakshina Kannada
Tribe Acridini MacLeay, 1821			
4.	**Genus *Acrida* (Linnaeus, 1758)**		
4.	*Acrida exaltata* (Walker, 1859)	Asia-Tropical, Indian Subcontinent, Sri Lanka	Chikkamagaluru*, Chikkaballapur, Dharwad,

			Dakshina Kannada, Kolar, Mysore and Shivamogga
Tribe Phlaeobini Brunner von Wattenwyl, 1893			
5.	**Genus *Phlaeoba* Stal, 1861**		
5.	*Phlaeoba antennata antennata* Brunner von Wattenwyl, 1893	Myanmar: Bhamo	Chikkamagaluru, Kodagu, Mysore and Shivamogga
6.	*Phlaeoba infumata* Brunner von Wattenwyl, 1893	Myanmar: Bhamo	Chikkamagaluru, Kolar, Mysore and Shivamogga
7.	*Phlaeoba panteli* Bolivar, 1902	India: Madras	Dharwad
8.	*Phlaeoba ramakrishnai* Bolivar, 1914	South Canara: Magadi	Dakshina Kannada
9.	*Phlaeoba rotundata* Uvarov, 1929	Tamil Nadu: Kodaikanal	Mysore
Tribe Truxalini Serville, 1838			
6.	**Genus *Truxalis* Fabricius, 1775**		
10.	*Truxalis indica* (Bolivar, 1902)	Tamil Nadu: Kodaikanal	Bellary, Dharwad and Kolar
7.	**Genus *Bababuddinia* Bolivar, 1917**		
11.	*Bababuddinia bizonata* Bolívar, 1917	India: Karnataka, Mysore, Bababuddin Hills	Chikkamagaluru
12.	*Bababuddinia dimorpha* Henry, 1933	India: Karnataka, Mysore, Bababuddin Hills	Chikkamagaluru
8.	**Genus *Capulica* Bolivar, 1917**		
13.	*Capulica alata* Uvarov, 1929	India: Tamil Nadu, Mysore Plateau, Masinigudi	Bellary, Kamalapuram
14.	*Capulica pulla* Bolívar, 1917	India: Andhra Pradesh, Bellary district, Kamalapuram	Bellary, Kamalapuram
II. Subfamily Calliptaminae Jacobson, 1905 (one genus and one species)			
9.	**Genus *Acorypha* Krauss, 1877**		
15.	*Acorypha glaucopsis* (Walker, 1870)	Africa	Dharwad
III. Subfamily Catantopinae Brunner von Wattenwyl, 1893 (11 genera and 16 species)			
10.	**Genus *Opharicus* Uvarov, 1940**		
16.	*Opharicus ballardi* (Bolivar, 1918)	India: Andhra Pradesh, Bellary district, Kamalapuram	Bellary: Kamalapuram and Yemmiganur
11.	**Genus *Pachyacris* Uvarov, 1923**		
17.	*Pachyacris vinosa* (Walker, 1870)	India: West Bengal	Dharwad
18.	*Pachyacris violascens* (Walker, 1870)	Sri Lanka	Dharwad
12.	**Genus *Palniacris* Henry, 1940**		
19.	*Palniacris maculatus* Henry, 1940	India: Kerala: Nelliampathi Hills	Karnataka
Tribe Oxyrrhepini Tinkham, 1940			
13.	**Genus *Oxyrrhepes* Stal, 1873**		
20.	*Oxyrrhepes obtusa* (Haan, 1842)	Malesia: Jawa	Dharwad and Shivamogga

26.	*Diabolocatantops pinguis* (Stal, 1860)	China	Uttara Kannada, Dakshina Kannada, Mangalore, Shivamogga* and Udupi*
27.	*Diabolocatantops pulchellus* (Walker, 1870)	India: Maharashtra, Hindustan	Dharwad
17.	**Genus *Stenocatantops* Dirsh, 1953**		
28.	*Stenocatantops splendens* (Thunberg, 1815)	China	Dakshina Kannada, Dharwad and Shivamogga
Tribe Genimenini Li, X. J. and Yin, X. C, 2009			
18.	**Genus *Genimen* Bolivar, 1918**		
29.	*Genimen prasinum* Bolívar, 1917	India: Karnataka, Mysore, Bababuddin Hills	Dakshina Kannada and Chikkamagaluru
19.	**Genus *Mesambria* Stål, 1878**		
30.	*Mesambria* sp.	-	Dharwad
Tribe Paraconophymatini Otte, 1995			
20.	**Genus *Paraconophyma* Uvarov, 1921**		
31.	*Paraconophyma scabra* (Walker, 1870)	India: West Bengal, Burdwan (Bardhaman)	Chikkamagaluru* Dharwad and Shivamogga
IV. Subfamily Coptacridinae Brunner von Wattenwyl, 1893 (3 genera and 6 species)			
21.	**Genus *Coptacra* Stal, 1873**		
32.	*Coptacra ensifera* Bolívar, 1902	India: Tamil Nadu, Madurai	Belgaum
33.	*Coptacra punctoria* (Walker, 1870)	India: South India	Mysore
22.	**Genus *Epistaurus* Bolivar, 1889**		
34.	*Epistaurus sinetyi* Bolivar, 1902	India: Tamil Nadu, Trichinopoly	Dharwad and Shivamogga*
23.	**Genus *Eucoptacra* Bolivar, 1902**		
35.	*Eucoptacra ceylonica* Kirby, 1914	Sri Lanka	Dharwad
36.	*Eucoptacra praemorsa* (Stal, 1861)	China: Hong Kong	Dharwad, Chikkamagaluru* and Shivamogga*
37.	*Eucoptacra saturata* (Walker, 1870)	India	Mysore and Shivamogga
V. Subfamily Cyrtacanthacridinae Kirby, 1910 (3 genera and 3 species)			
24.	**Genus *Chondracris* Uvarov, 1923**		
38.	*Chondracris rosea* (De Geer, 1773)	China	Shivamgga
Tribe Cyrtacanthacridini Kirby, 1910			
25.	**Genus *Anacridium* Uvarov, 1923**		
39.	*Anacridium flavescens* (Fabricius, 1793)	India	Dharwad
26.	**Genus *Cyrtacanthacris* Walker, 1870**		
40.	*Cyrtacanthacris tatarica tatarica* (Linnaeus, 1758)	Sri Lanka	Dharwad and Shivamogga

VI. Subfamily Eyprepocnemidinae Brunner von Wattenwyl, 1893			
27.	**Genus *Tylotropidius* Stal, 1860**		
41.	*Tylotropidius varicornis* (Walker, 1870)	India: Maharashtra, South Hindustan	Dakshina Kannada, Dharwad and Shivamogga
Tribe Eyprepocnemidini Brunner von Wattenwyl, 1893			
28.	**Genus *Eyprepocnemis* (Fieber, 1853)**		
42.	*Eyprepocnemis alacris alacris* (Serville, 1838)	India: South India	Chikkamagaluru*, Dakshina Kannada, Dharwad, Kolar and Shivamogga
29.	**Genus *Heteracris* Walker, 1870**		
43.	*Heteracris pulchra* (Bolivar, 1902)	India: Tamil Nadu, Kodaikanal	Mysore and Shivamogga *
VII. Subfamily Gomphocerinae Fieber, 1853 (8 genera and 10 species)			
30.	**Genus *Gelastorhinus* Brunner von Wattenwyl, 1893**		
44.	*Gelastorhinus semipictus* (Walker, 1870)	India	Dharwad, Kolar and Dakshina Kannada
Tribe Arcypterini Shumakov, 1963			
31.	**Genus *Aulacobothrus* Bolivar, 1902**		
45.	*Aulacobothrus luteipes inferrus* Bolivar, 1902	India: Tamil Nadu: Kodaikanal	Karnataka
46.	*Aulacobothrus luteipes luteipes* (Walker, 1871)	India: Maharashtra, Bombay, Khandala	Dakshina Kannada, Dharwad, Mysore, Shivamogga, Udupi* and Uttaraa Kannada
47.	*Aulacobothrus socius* Bolivar, 1902	India: Tamil Nadu, Kodaikanal	Shivamogga
32.	**Genus *Crucinotacris* Jago, 1996**		
48.	*Crucinotacris decisa* (Walker, 1871)	India: Maharashtra, Bombay	Shivamogga
33.	**Genus *Leionotacris* Jago, 1996**		
49.	*Leionotacris bolivari* (Uvarov, 1921)	India: Bihar, Chapra	Chikkamagaluru and Shivamogga*
34.	**Genus *Phonogaster* Henry, 1940**		
50.	*Phonogaster cariniventris* Henry, 1940	India: Karnataka, Dhimbam, Biligiriranga Hills	Uttara Kannada
35.	**Genus *Stenohippus* Uvarov, 1926**		
51.	*Stenohippus trapezoidalis* (Bolivar, 1914)	India: Karnataka, Hadagalli	Vijayanagara
36.	**Genus *Leva* Bolivar, 1909**		
52.	*Leva indica* (Bolivar, 1902)	India: Tamil Nadu, Madurai	Dakshina Kannada, Mysore and Shivamogga*
Tribe Ochrilidini Brunner von Wattenwyl, 1893			
37.	**Genus *Gonista* Bolivar, 1898**		
53.	*Gonista sagitta* (Uvarov, 1912)	Asia-Temperate: Middle Asia, Turkmenistan, Farab on Amu Darya	Mysore

VIII. Subfamily Hemiacridinae Dirsh, 1956 (4 genera and 7 species)			
Tribe Hieroglyphini Bolivar, 1912			
38.	**Genus *Calamippa* Henry, 1940**		
54.	*Calamippa prasina* (Bolivar, 1902)	India: Tamil Nadu, Madurai	Chamarajnagara
39.	**Genus *Clonacris* Uvarov, 1943**		
55.	*Clonacris kirbyi* (Finot, 1903)	India: Tamil Nadu, Kodaikanal	Karnataka
40.	**Genus *Hieroglyphus* Krauss, 1877**		
56.	*Hieroglyphus banian* (Fabricius, 1798)	India: Maharashtra, Bombay	Dharwad, Shivamogga and Uttara Kannada
57.	*Hieroglyphus concolor* (Walker, 1870)	India: Maharashtra, Hindustan	Karnataka
58.	*Hieroglyphus nigrorepletus* (Bolivar, 1912)	India: Karnataka, Bellary	Bellary
41.	**Genus *Parahieroglyphus* Carl, 1916**		
59.	*Parahieroglyphus bilineatus* (Bolivar, 1912)	India: West Bengal	Dharwad
60.	*Parahieroglyphus colemani* (Bolivar, 1912)	India: Karnataka, Anavatti	Shivamogga
IX. Subfamily Oedipodinae Walker1871 (9 genera and 15 species)			
42.	**Genus *Chloebora* Saussure, 1884**		
61.	*Chloebora crassa* (Walker, 1870)	India: West Bengal	Belagavi and Dharwad
43.	**Genus *Dittopternis* Saussure, 1884**		
62.	*Dittopternis venusta* (Walker, 1870)	India: South Hindustan	Dakshina Kannada, Dharwad, Kolar, Mysore, Shivamogga and Uttara Kannada
63.	*Dittopternis zebrata* Saussure, 1884	East India	Dakshina Kannada
44.	**Genus *Morphacris* Walker, 1870**		
64.	*Morphacris citrina* Kirby, 1910	Lebanon-Syria: Syria	Kolar, Mysore, Shivamogga and Uttara Kannada
65.	*Morphacris fasciata* (Thunberg, 1815)	Southern Africa: Western Cape Province, Cape of Good Hope	Dakshina Kannada and Dharwad
Tribe Acroylini Johnaton, 1956			
45.	**Genus *Acrotylus* Fieber, 1853**		
66.	*Acrotylus humbertianus* Saussure, 1884	Sri Lanka	Dakshina Kannada, Dharwad and Shivamogga
Tribe Epacromiini Brunner von Wattenwyl, 1893			
46.	**Genus *Aiolopus* Fieber, 1853**		
67.	*Aiolopus simulatrix simulatrix* (Walker, 1870)	India: Maharashtra, South Hindustan	Dharwad
68.	*Aiolopus thalassinus tamulus* (Fabricius, 1798)	India	Bengaluru, Kodagu, Dakshina Kannada, Dharwad, Kolar, Shivamogga and Uttara Kannada

69.	*Aiolopus thalassinus thalassinus* (Fabricius, 1781	Europe: Switzerland, Maggia Delta	Dharwad
Tribe Locustini Kirby, 1825			
47.	**Genus *Gastrimargus* Saussure, 1884**		
70.	*Gastrimargus africanus africanus* (Saussure, 1888)	Southern Africa: Cape Province	Dakshina Kannada, Dharwad, Mysore, Shivamogga and Uttara Kannada
71.	*Gastrimargus marmoratus* (Thunberg, 1815)	Africa: Cape Province	Karnataka
48.	**Genus *Oedaleus* Fieber, 1853**		
72.	*Oedaleus abruptus* (Thunberg, 1815)	China	Dakshina Kannada, Dharwad and Shivamogga
73.	*Oedaleus senegalensis* (Krauss, 1877)	Africa: Senegal, St Louis	Dharwad
49.	**Genus *Heteropternis* Stål, 1873**		
74.	*Heteropternis respondens* (Walker, 1859)	India: Sri Lanka.	Dakshina Kannada and Dharwad
Tribe Trilophidiini Stal, 1873			
50.	**Genus *Trilophidia* Stal, 1873**		
75.	*Trilophidia annulata* (Thunberg, 1815)	China, Japan, Java	Bengaluru, Chikkamagaluru, Kodagu, Dharwad, Dakshina Kannada*, Kolar, Mysore, Shivamogga, Udupi* and Uttara Kannada
X. Subfamily Oxyinae Brunner von Wattenwyl, 1893 (3 genera and 7 species)			
51.	**Genus *Chitaura* Bolivar, 1918**		
76.	*Chitaura indica* Uvarov, 1929	India: Karnataka, Coorg, Siddapura	Chikkamagaluru, Dakshina Kannada*, Hassan*, Mysore
Tribe Oxyini Brunner von Wattenwyl, 1893			
52.	**Genus *Gesonula* Uvarov, 1940**		
77.	*Gesonula punctifrons* (Stal, 1861)	China	Dakshina Kannada, Kolar, Shivamogga, Udupi* and Uttara Kannada
53.	**Genus *Oxya* Serville, 1831**		
78.	*Oxya fuscovittata* (Marschall, 1837)	India orientalis vel Caput bonae spei	Chikkamagaluru*, Dakshina Kannada, Dharwad, Shivamogga, Udupi* and Uttara Kannada
79.	*Oxya hyla hyla* (Serville, 1831)	Africa: Senegal	Chikkamagaluru*, Dakshina Kannada, Dharwad, Kolar, Shivamogga, Udupi* and Uttara Kannada

80.	*Oxya japonica japonica* (Thunberg, 1824)	Japan	Chikkamagaluru*, Shivamogga*, Uttara Kannada
81.	*Oxya nitidula* (Walker, 1870)	India: Maharashtra, Hindustan	Chikkamagaluru, Kodagu, Dharwad, Dakshina Kannada*, Mysore, Shivamogga and Uttara Kannada
82.	*Oxya velox* (Fabricius, 1787)	China	Dakshina Kannada and Kolar
XI. Subfamily Spathosterninae Rehn, 1957 (1 genus and 2 species)			
Tribe Spathosternini rehn, 1957			
54.	**Genus *Spathosternum* Krauss, 1877**		
83.	*Spathosternum abbreviatum* (Uvarov, 1929)	India: Tamil Nadu, Nilgiris, Snowdon Peak	Karnataka
84.	*Spathosternum prasiniferum prasiniferum* (Walker, 1871)	India: Maharashtra, Bombay	Chikkamagaluru, Kodagu, Dharwad, Dakshina Kannada, Shivamogga, Udupi* and Uttara Kannada
XII. Subfamily Teratodinae Brunner von Wattenwyl, 1893 (1 genus and one species)			
55.	**Genus *Teratodes* Brulle, 1835**		
85.	*Teratodes monticollis* (Gray, 1832)	India: Ceylon	Shivamogga
XIII. Subfamily Tropidopolinae Jacobson, 1905 (1 genus and one species)			
Tribe Tristriini Mishchenko, 1945			
56.	**Genus *Tristria* Stal, 1873**		
86.	*Tristria pulvinata* (Uvarov, (1921)	India: Punjab	Dakshina Kannada, Dharwad, Kolar, Shivamogga and Uttara Kannada
Superfamily Pyrgomorphoidea Brunner von Wattenwyl, 1874 B. Family Pyrgomorphidae Brunner von Wattenwyl, 1874			
I. Subfamily Orthacridinae Bolívar, 1905 (3 genera, one sub genus and 6 species)			
Tribe Orthacridini Bolivar, 1905			
1.	**Genus *Neorthacris* Kevan and Singh, 1964**		
87.	*Neorthacris acuticeps acuticeps* (Bolivar, 1902)	India: Tamil Nadu, Madurai	Chikkamagaluru*, Dakshina Kannada*, Kodagu, Kolar, Shivamogga*
88.	*Neorthacris acuticeps nilgiriensis* (Uvarov, 1929)	India: Tamil Nadu, Nilgiri Hills	Dharwad
i.	**Subgenus *Pseudorthacris* Kevan and Singh, 1964**		
89.	*Orthacris* (*Pdeudorthacris*) *ruficornis* Bolivar, 1902	India: Tamil Nadu, Kodaikanal	Kodagu
Tribe popoviini Kevan and Akber, 1964			
2.	**Genus *Colemania* Bolivar, 1910**		

90.	*Colemania sphenarioides* Bolivar, 1910	India: Karnataka, Honnali	Bellary, Davanagere and Mysore
3.	**Genus *Ramakrishnaia* Bolivar, 1917**		
91.	*Ramakrishnaia gracilis* Kevan, 1964	India: Karnataka, Kodagu (Coorg)	Kodagu
92.	*Ramakrishnaia notabilis* Bolivar, 1917	India: Karnataka Mysore, Bababuddin Hills	Chikkamagaluru and Mysore
II. Subfamily Pyrgomorphinae Brunner von Wattenwyl, 1874 (7 genera and 9 species)			
Tribe Atractomorphini Bolivar, 1905			
4.	**Genus *Atractomorpha* Saussure, 1862**		
93.	*Atractomorpha crenulata* (Fabricius, 1793)	India: Tamil Nadu, (Tharangambadi) Tranquebar	Chikkamagaluru*, Dakshina Kannada, Dharwad, Kolar, Mysore, Shivamogga, Udupi* and Uttara Kannada*
Tribe Chlorizeinini Kevan and Akber, 1964			
5.	**Genus *Feacris* Kevan, 1969**		
94.	*Feacris malabarensis* Kevan, 1953	India: Karnataka, Mangalore	Mysore and Dakshina Kannada
Tribe Chrotogonini Bolivar, 1904			
6.	**Genus *Chrotogonus* Serville, 1838**		
95.	*Chrotogonus trachypterus trachypterus* (Blanchard, 1837)	India: Maharashtra, Mumbai	Dharwad, Kolar, Shivamogga and Uttara Kannada
96.	*Chrotogonus oxypterus* (Blanchard, 1837)	India: Kerala, Mahe	Bellary, Dakshina Kannada, Dharwad, Kolar and Shivamogga
Tribe Poekilocerini Burmeister, 1840			
7.	**Genus *Poekilocerus* Serville, 1831**		
97.	*Poekilocerus pictus* (Fabricius, 1775)	India: Karnataka, Bellary	Bellary
Tribe Pyrgomorphini Brunner von Wattenwyl, 1874			
8.	**Genus *Pyrgomorpha* Serville, 1838 (1839)**		
98.	*Pyrgomorpha bispinosa bispinosa* (Walker, 1870)	India: Maharashtra, South Hindusthan	Dharwad, Kolar and Mysore
99.	*Pyrgomorpha (Pyrgomorpha) conica* (Olivier, 1791)	Europe: France, Cannes	Karnataka
9.	**Genus *Zarytes* Bolivar, 1904**		
100.	*Zarytes squalinus squalinus* (Saussure, 1884)	India	Karnataka
Tribe Taphronotini Bolivar, 1904			
Subtribe Aularchina Kevan and Akber, 1964			
10.	**Genus *Aularches* Stal, 1873**		
101.	*Aularches miliaris miliaris* (Linnaeus, 1758)	Asia-Tropical	Chikkamagaluru* and Dharwad

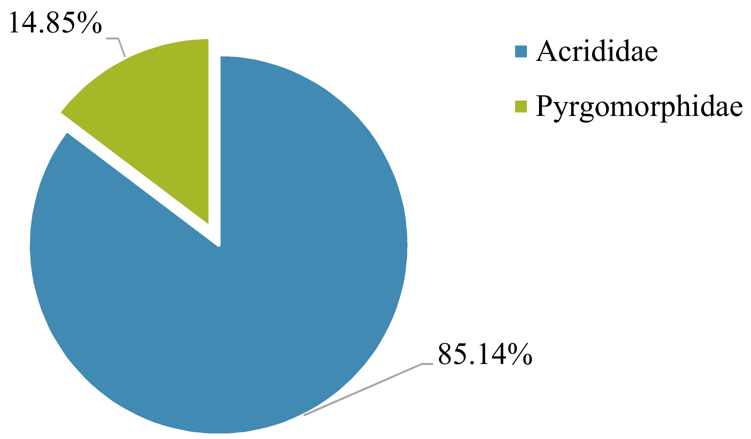

Figure 2: Per cent species composition of the family Acrididae and Pyrgomorphidae from Karnataka

In Pyrgomorphidae, Pyrgomorphinae had a maximum number of species (nine) and genera (seven), sharing 60 per cent; while, Orthacridinae had six species and three genera sharing 40 per cent (Figure-3). In Acrididae, the Catantopinae contributed the highest sum of species (16), which accounts for 18.6 per cent and 11 genera, followed by Oedipodinae, with 15 species, which shares about 17.44 per cent in 9 genera. These results are in confirmity with the findings of Prabhakar and Chandra (2013). In comparison, the least number of species was reported from the subfamilies Calliptaminae, Teratodinae and Tropidopolinae, comprising one species each accounting for 1.16 per cent each (Figure-4). In the studies of Shishodia *et al*. (2010), Prabhakar and Chandra (2013) and Mandal *et al*. (2013), the subfamilies mentioned above showed similar dominance in the species count.

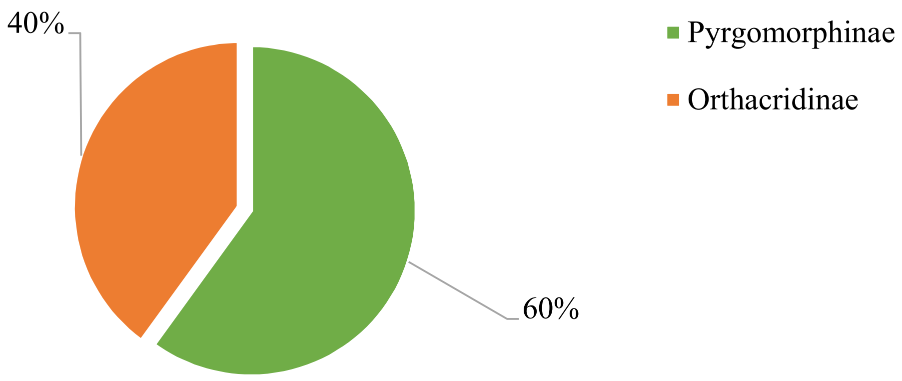

Figure 3: Per cent species composition of the family Acrididae and Pyrgomorphidae from Karnataka

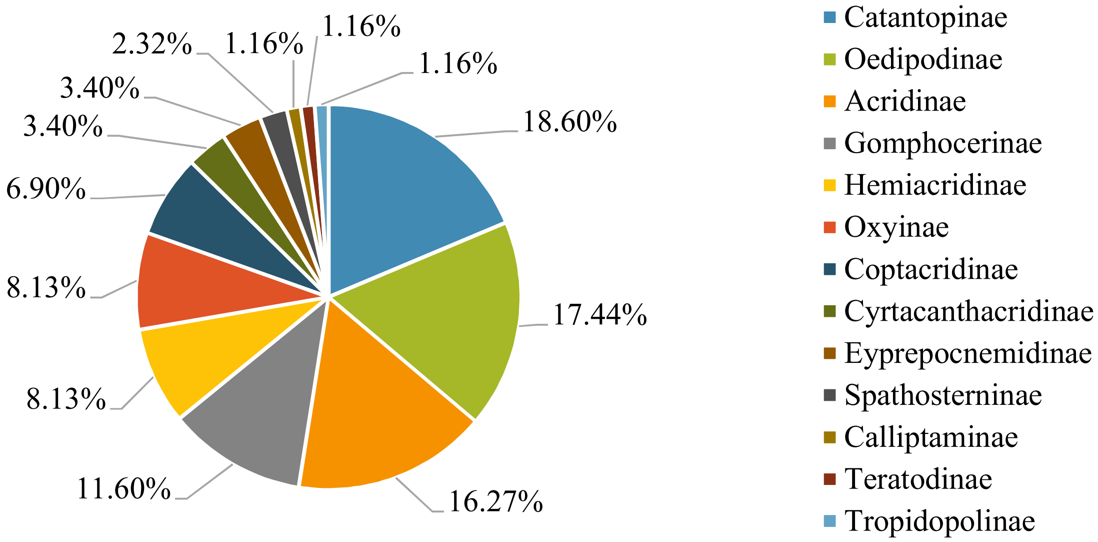

Figure 4: Showing per cent species composition within subfamilies of Acrididae of Karnataka

In the current study, Acridinae encompasses 15 species, with five new additions compared to earlier studies by Shishodia *et al.* (2010) and Prabhakar and Chandra (2013). Catantopinae comprises 16 species, expanding the checklist by four species compared to the 12 species identified in previous studies by Prabhakar and Chandra (2013) and Shishodia *et al.* (2010). Though Coptacridinae comprises six species, the previous research recorded only three and two species by Prabhakar and Chandra (2013) and Shishodia et al. (2013), respectively.

Thus, three additional species were added to the checklist. Cyrtacanthacridinae includes three species, two of which were previously documented by Shishodia *et al.* (2010) and Prabhakar and Chandra (2013) and *Chondracris rosea* (De Geer) is a new addition to the checklist. Three species were represented by Eyprepocnemidinae and the findings are consistent with those of Mandal *et al.* (2013). Prabhakar and Chandra (2013) and Shishodia *et al.* (2010) documented eight species and nine species, respectively from Gomphocerinae. However, this study identified ten species. Hemiacridinae is comprised of seven species, with the addition of *Parahieroglyphus bilineatus* (Bolivar), which was not included in the previous research conducted by Shishodia *et al.* (2010) and Prabhakar and Chandra (2013). Oedipodinae are represented by 15 species, while, the earlier studies by Shishodia *et al.* (2010) and Prabhakar and Chandra (2013) recorded only five and seven species, respectively; thus, eight species were added to the present checklist. Oxyinae contributed seven species, but previous studies by Shishodia *et al.* (2010), Prabhakar and Chandra (2013) and Mandal *et al.* (2013) recorded only five species. Earlier, *Gesonula punctifrons* were placed under Hemiacridinae and later incorporated into Oxyinae. Hence, it is counted under Oxyinae. So, added two more species to the current checklist. Spathosterninae comprises two species in Karnataka, which is consistent with the previous findings of Shishodia *et al.* (2010) and Prabhakar and Chandra (2013). In the present study, Pyrgomorphinae represents nine species. But earlier studies by Shishodia *et al.* (2010) and Prabhakar and Chandra (2013) have recorded only six species. Hence, we added three more species to checklist through the current research. Orthacridinae represents six species from three genera. Of which, three were mentioned by previous workers, Shishodia *et al.* (2010) and Prabhakar and Chandra (2013); thereby, adding three more species to the present checklist.The study also exemplifies that several species were recorded for the first time in the surveyed districts. In Chikkamagaluru, 13 species were collected, of which nine are new records: *Acrida exaltata*, *Atractomorpha crenulata*, *Aularches miliaris miliaris*, *Eyprepocnemis alacris*

alacris, *Eucoptacra praemorsa*, *Oxya fuscovittata*, *O. japonica japonica*, *Neorthacris acuticeps acuticeps* and *Paraconophyma scabra,* whereas previous research has identified five species (Mand al *et al*., 2013).

Four of the eleven species that were collected in Dakshina Kannada: *Chitaura indica*, *O. nitidula*, *Trilophidia annulata* and *N. acuticeps acuticeps* are new records, whereas six species had been recorded in previous studies (Mayya *et al*., 2005). One species, *A. miliaris miliaris,* was collected in Kodagu and is a new record. Three of the 25 species that were collected in Shivamogga: *O. japonica japonica*, *Heteracris pulchra* and *Diabolocatantops pinguis* are new records. However, Mandal *et al*. (2013) previously recorded 22 species. In Uttar Kannada, eight species were collected, of which one is a new record: *A. crenulata*. Previous studies have documented the remaining seven species (Bhatnagar, 2013). The Hassan and Udupi districts had no prior records of short-horned grasshoppers. In the current study, eleven species, *viz., Spathosternum prasiniferum prasiniferum, Gesonula punctifrons, O. fuscovittata*, *O. hyla hyla*, *D. innotabilis*, *D. pinguis*, *Aulacobothrus lutipes lutipes*, *T. annulata* and *A. crenulata* and one species *viz., C. indica* from Hassan districts were collected, all of which are new records for the districts. This might be due to a lack of surveys by earlier workers in this region.

Conclusion

In the literature survey and from our collection, a total of 101 species belonging to 13 subfamilies of Acrididae viz., Acridinae, Calliptaminae, Catantopinae, Coptacridinae, Cyrtacanthacridinae, Eyprepocnemidinae, Gomphocerinae, Hemia cridinae, Oedipodinae, Oxyinae, Spathosterninae, Teratodinae and Tropidopolinae and two subfamilies of Pyrgomorphidae viz., Orthacridinae and Pyrgomorphinae were recorded. In Acrididae, the subfamily Catantopinae showed the maximum abundance followed by Oedipodinae; whereas, in Pyrgomorphidae, Pyrgomorphinae was dominant. Several species were recorded for the first time from the surveyed districts. The study demonstrated the presence of various new records from the districts surveyed. This also suggests the need for further intensive survey and taxonomic studies of grasshoppers in Karnataka to know the actual diversity and these records will aid as baseline data.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Gene actions and combining ability effects on grain yield and its constituent traits in inbred lines of quality protein maize

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ABSTRACT

In the present study twenty-eight hybrid combinations resulting from the half-diallel mating of eight quality protein maize (QPM) inbred lines were chosen in order to examine the potential to combine and gene activity for ten yield and component attributes. As part of the All India Coordinated Research Project (AICRP) on maize during the kharif-2020 season, the experiment was done at the research farm of college of Agriculture, Odisha University of Agriculture & Technology (OUAT) Bhubaneswar, using a randomized complete block design replicated thrice. Every observation recorded was subjected to statistical evaluation and it was revealed that the mean squares derived from the general combining ability (gca) and specific combining ability (sca) were highly significant ($p \geq 0.01$). Estimates of sca effects were greater than that of gca effects for all of the variables used in the study, suggesting to the predominance of dominant gene action. The inbred lines Q4-DQL 2221-1-1(833.792), Q2-DQL 2099 (517.658) and Q3- DQL 2159 (350.325) shows high gca effects for yield and its attributing traits due to more additive gene action thus identified as good general combiners for yield. Twelve of the twenty-eight crosses showed significant ($p \geq 0.01$ and 0.05) positive sca effect on grain yield. The best experimental crosses for grain yield based on per se performance and sca effects were Q2 x Q8 (2106.748), Q1 x Q6 (2053.048), Q3 x Q7 (2027.082), and Q3 x Q6 (1719.884).

Introduction

The most robust and adaptable food crop, maize (*Zea mays* L.; 2n = 20; Poaceae), is grown across the world in different agro-ecological zones. It is India's third most popular cereal, behind rice and wheat (Poehlman, 2006). Maize is a miracle crop, popularly known as the "Queen of Cereals" due to its very high yield potential (Shinde *et al.*, 2021). The protein content in maize is crucial for the country's food and dietary wellbeing since more than 85 per cent of it is used directly as food and feed. On the other hand, Normal maize has a high zein proportion that is deficient in tryptophan and lysine content (Das *et al.*, 2021). In 1964, scientists at Purdue University identified the opaque-2 (o-2) gene mutation, which provided endless potential for enhancing the protein content of maize kernels and eventually led to the creation of Quality Protein Maize (QPM). QPM protein has a biological value of 80%, which is comparable to milk protein (90%) and nearly double that of ordinary maize protein (50%) (Agarwal *et al.*, 2018). The diallel approach is used to evaluate both general and specific combining abilities as well as supplementary hereditary characteristics. A hybrid's performance is

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directly associated with the GCA and SCA of the inbred lines used in the crossing, therefore estimates of combining ability are very helpful in figuring out how useful a pair of parents will be in a hybrid combination and in selecting better parents for the generation of hybrids (Bahari *et al.,* 2012). The SCA is predominantly a result of dominance genetic variance, whereas the GCA is mostly a consequence of additive genetic variance and additive x additive epistasis (Sprague and Tatum, 1942). By examining the variance components of GCA and SCA, it is possible to determine the prevalence of additive or dominant gene activity. Standard selection procedures can fix the additive fraction of genetic variation, but the non-additive fraction cannot, and its presence for controlling characteristics needs the employment of hybrid vigour in heterosis breeding. The study of gene function concerning several morphological criteria might aid in developing a breeding strategy for high-yielding, high-quality protein maize varieties. Plant breeders may find this information useful when planning hybridization programs. As a result, the current investigation was carried out to learn more about the gene action and combining ability for grain yield and other features that contribute to yield.

Material and Methods

The study was carried out by utilizing eight parent QPM inbred lines *viz*., Q1 (DQL 2261), Q2 (DQL 2099), Q3 (DQL 2159), Q4 (DQL 2221-1-1), Q5 (DQL 70160), Q6 (DQL 71266), Q7 (DQL 72154), and Q8 (DQL-72242), to produce 28 F_1 hybrids using an 8 x 8 half diallel mating system. The eight parents and their 28 crosses were grown in randomized complete block designs, replicated thrice during *kharif* 2020 at research farm, AICRP on Maize, OUAT, Bhubaneswar. The plants are grown in two rows measuring 4 metres in length, with a 60 cm by 20 cm space between them. For each replication, observations on yield and its contributing traits were made. *viz*., grain yield (GY) (kg/ha), number of kernel rows per cob (NKRPC), number of grains per row (NGPR), plant height (PH) (cm), Cob diameter (CD) (cm), Cob length (CL) (cm), ear height (EH) (cm), days to 50% pollen shedding (50%PS), days to 50% silk emergence (50%SE), and days to 75% dry husk (75% DH). The mean squares for GCA and SCA were compared to the corresponding error variances obtained from an ANOVA that had been averaged down. The mean data were submitted to combining ability analysis using Griffing's Model I's Method II (1956) using R-software.

Results and Discussion

The analysis of variance (Table 1) revealed that parents and crosses were significantly different from each other for all the traits under study. The table showed that the mean sums of squares due to GCA and SCA for all characters under study were highly significant ($p \geq 0.01$) indicating the prevalence of both additive and dominant gene action. The influence of both type of gene action also reported by Hemlatha *et al.* (2014), Patel *et al.* (2016), Ali *et al.* (2020) and Scaria *et al.* (2020). Kamal *et al.* (2023) reported non-significant mean squares for yield and component traits. Table 2 represents combining ability variance of GCA, SCA and their ratio. It was found that for all of the traits evaluated, SCA variances ($\boldsymbol{\sigma^2_{sca}}$) were higher than that of GCA variances ($\boldsymbol{\sigma^2_{gca}}$) and the SCA to GCA variance ratios were more than one for all characters undertaken. This finding pointed out that dominant or non-additive types of gene activity predominate in these genotypes. This result is in contrast with Tilahun *et al.* (2017) and Karim *et al.* (2018) who reported prevalence of additive gene action for all the traits except days to silking. Dominant or non-additive gene action was also reported by Yerva *et al.* (2016), Kumar *et al.* (2017), Hassan *et al.* (2019) and Arunkumar *et al.* (2022). The gca effects were presented in the Table 3 for each of the ten yield and component traits. The significant negative gca effects for early maturity traits, such as 50%PS, 50%SE, and 75%DH were observed in three parents Q2, Q3, and Q4 out of the eight parents. The highest significant gca effects for 50%PS (-1.50), 50%SE (-1.62), and 75%DH (-1.30) were reported in parent Q4. These parents (Q2, Q3, and Q4) are good combiners for transfer of early maturity traits. Krupakar *et al.* (2013), E1-Shamarka *et al.* (2015) and Patel *et al.* (2016) also reported significant negative gca effects for these traits. When it comes to PH and EH, significant negative gca effects were

Table 1: Analysis of variance for yield and component traits in QPM inbred lines

Sl. No.	Source of variation	d.f.	50%PS	50%SE	75%DH	PH	EH	CL	CD	NKRPC	NGPR	GY
1	Genotypes	35	17.855**	17.101**	17.431**	1453.762**	853.165**	13.009**	9.633**	10.304**	117.646**	6160725.997**
2	Parents	7	3.238**	3.405**	4.423**	362.280**	475.119**	11.174**	10.050**	13.466**	100.964**	219755.804**
3	Hybrids	27	11.828**	10.873**	16.728**	367.898**	393.680**	5.407**	4.350**	2.046**	44.342**	4049471.480**
4	Parents *vs.* Hybrids	1	282.881**	281.153**	127.461**	38412.461**	15905.567**	231.084**	149.352**	211.131**	2213.641**	104751389.303**
5	GCA	7	23.179**	24.264**	18.743**	3074.455**	1729.436**	28.193**	21.480**	29.818**	250.613**	11052372.788**
6	SCA	28	16.524**	15.311**	17.103**	1048.588**	634.097**	9.213**	6.671**	5.426**	84.405**	4937814.299**
7	Error	70	1.369	1.014	1.311	89.628	52.008	0.474	0.223	0.379	2.533	283410.323

Table 2: GCA, SCA variance and their ratio for yield and component traits in QPM inbred lines

Characters	σ^2_{gca}	σ^2_{sca}	$\frac{\sigma^2_{gca}}{\sigma^2_{sca}}$
50%PS	2.181	15.155	0.143913
50%SE	2.325	14.297	0.162622
75%DH	1.7432	15.792	0.110385
PH	298.4827	958.96	0.311257
EH	167.7428	582.089	0.288174
CL	2.7719	8.739	0.317187
CD	2.1257	6.448	0.329668
NKRPC	2.9439	5.047	0.583297
NGPR	24.808	81.872	0.30301
GY	1076896	4654404	0.231371

Table 3: gca effects of 8 parental lines for yield and component traits in QPM inbred lines

S. No.	Parents	50%PS	50%SE	75%DH	PH	EH	CL	CD	NKRPC	NGPR	GY
1	Q1	0.758**	0.608**	0.800**	12.058**	1.958	0.448**	0.403**	0.355**	1.543**	28.158
2	Q2	-0.575**	-0.658**	-0.700**	5.425**	1.925	1.508**	1.083**	1.188**	3.993**	517.658**
3	Q3	-0.675**	-0.592**	-0.500*	8.058**	7.925**	-0.082	0.223**	0.835**	1.600**	350.325**
4	Q4	-1.508**	-1.625**	-1.300**	7.992**	11.825**	0.848**	0.350**	0.648**	1.800**	833.792**
5	Q5	-0.142	-0.025	0.333	1.358	0.225	0.348**	0.670**	0.222*	0.367	234.225*
6	Q6	0.458*	0.642**	-0.067	-10.542**	-8.042**	-1.265**	-1.430**	-1.778**	-4.583**	-368.142**
7	Q7	1.092**	1.042**	1.000**	-10.708**	-6.575**	-0.798**	-0.363**	-0.665**	-3.377**	-679.342**
8	Q8	0.592**	0.608**	0.433*	-13.642**	-9.242**	-1.008**	-0.937**	-0.805**	-1.343**	-916.675**
SE G(I)		0.200	0.172	0.196	1.617	1.232	0.118	0.081	0.105	0.272	90.918

*** Significant at 5% level of probability (p ≥0.05) ** Significant at 1% level of probability (p ≥0.01) * SE G(I) Standard error for gca effects**

observed in parents Q6, Q7, and Q8.The highest significant negative gca effects for PH (Q8 - 13.642)and EH (-9.242) were reported in the parent Q8. Yerva *et al.* (2016) and Scaria *et al.* (2020) also reported significant negative gca effects for plant and ear height. Karim *et al.* (2018) found non-significant gca effect for plant height. The parents (Q6, Q7, and Q8) showed good combining ability for lowered plant and ear height characters and can be utilized for development of short stem-type plants. The significant positive gca effects for yield and its attributing traits *viz.*, CL, CD, NKRPC, and NGPR were observed in parents Q2, and Q4. Similarly, parent Q3 also showed significant positive gca effects for all the traits except CL while parent Q5 showed significance for all the traits except NGPR. The highest positive significant gca effects for GY was reported in the parent Q4 (833.79) followed by Q2 (517.65) and Q3 (350.32) and the highest significant positive gca effects were for yield attributing traits viz., CL (1.50), CD (1.08), NKRPC (1.18), and NGPR (3.99) were observed in the parent Q2. Singh *et al.* (2014) and E1-Shamarka *et al.* (2015), Basser *et al.* (2021) and Kamal *et al.* (2023) also reported positive gca effects for yield component traits. Parents Q2 and Q4 were best general combiners for yield and its attributing traits. These parents can be utilized as donor parents for accumulation of favorable genes. For each of the ten yield and component characters, specific combining ability effects have been computed and are presented in Table 4. Eight, ten and eleven crosses showed significant negative sca effects for early maturity traits viz., 50%PS, 50%SE, and 75%DH respectively. Cross Q3 × Q8 (-4.22) recorded highest significant negative sca effects for 50%PS followed by the crosses Q1 × Q6 (-4.18), and Q5 × Q6 (-3.59). Cross Q1 × Q7 (-4.04) recorded highest significant negative sca effects for 50%SE followed by the crosses Q3 × Q8 (-3.74), and Q5 × Q6 (-3.68). Cross Q5 × Q6 (-4.52) recorded highest significant negative sca effects for 75%DH followed by the crosses Q3 × Q8 (-4.19), and Q1 × Q6 (-2.99). The parents involved in theses crosses also showed good general combining ability effects and performed substantially better in specific crosses. E1-Shamarka *et al.* (2015), Basser *et al.* (2021) and Arunkumar *et al.* (2022) also reported desirable significant negative sca effects for earliness in their experiment while Karim *et al.* (2018) reported non-significant sca effect for days to 50% silking Most of these crosses have at least one parent with low gca effects. Significant negative sca effects for PH were observed in five crosses, namely Q5 x Q7 (-39.47), Q5 x Q8 (-23.20), Q6 x Q7(-13.57) Q1 x Q3 (-12.94) and Q3 x Q4 (-10.54), and for EH four crosses, namely Q6 x Q7(-29.50), Q5 x Q7(-26..43), Q5 x Q8 (-18.77) and Q2 x Q4 (-8.87) showed significant negative sca effects. Low EH and shorter plants are correlated to lodging resistance (Arunkumar *et al.*, 2022). These crosses showed best specific combing ability for shorter plant and ear height traits. The number of crosses showing significant positive sca effects for GY and other yield attributing traits viz., CL, CD, NKRPC, and NGPR were twelve, eleven, fourteen, eleven, and fifteen respectively. For CL,

Table 4: sca effects of 28 F1 crosses for yield and component traits in Quality Protein Maize

Sl. No.	Crosses	50%PS	50%SE	75%DH	PH	EH	CL	CD	NKRPC	NGPR	GY
1	Q1 x Q2	2.511**	2.985**	1.641**	-7.974	2.996	-1.547**	-2.353**	-1.801**	-7.944**	-1101.751**
2	Q1 x Q3	-1.722**	-1.748**	1.107*	-12.941**	-3.337	-0.357	-1.093**	-0.047	0.816	-576.419*
3	Q1 x Q4	1.111	1.285**	-1.426**	5.126	-2.570	-0.654*	0.880**	0.806**	2.349**	928.448**
4	Q1 x Q5	1.411**	1.352**	0.274	13.426**	25.030**	1.646**	1.193**	-0.101	2.116**	1495.349**
5	Q1 x Q6	-4.189**	-3.648**	-2.993**	16.993**	6.963*	3.259**	4.060**	1.833**	7.399**	2053.048**
6	Q1 x Q7	-3.489**	-4.048**	-1.393**	15.826**	-0.837	0.526	-0.407	-0.614*	2.226**	1059.915**
7	Q1 x Q8	-0.656	-0.948*	1.174*	17.426**	1.163	1.369**	0.467*	-0.141	3.559**	-411.419
8	Q2 x Q3	1.278*	1.185*	-2.393**	15.026**	9.030**	0.749*	0.793**	-0.747**	2.199**	556.748*
9	Q2 x Q4	-0.222	-0.115	2.741**	-0.907	-8.870**	-0.014	-0.967**	-0.427	-4.434**	-238.052
10	Q2 x Q5	-0.256	-0.381	-0.226	6.393	-1.270	-0.581	0.413	-0.534	0.666	1026.182**
11	Q2 x Q6	-1.189*	-1.381**	-1.826**	10.626*	-2.337	0.366	-0.387	0.999**	4.583**	259.882
12	Q2 x Q7	-0.156	-0.448	1.107*	6.793	1.530	0.066	-0.353	1.686**	-6.057**	-1235.251**
13	Q2 x Q8	0.344	0.319	2.674**	29.393**	23.530**	1.109**	1.187**	0.759**	3.243**	2106.748**
14	Q3 x Q4	2.878**	2.485**	4.207**	-10.541*	-6.537	-0.257	-0.507*	0.259	-4.241**	-839.051**
15	Q3 x Q5	-0.156	0.552	0.907	-1.241	-5.604	-0.491	-1.793**	0.153	-5.241**	-2633.818**
16	Q3 x Q6	-1.756**	-1.115*	-2.026**	22.326**	18.663**	2.556**	1.940**	2.219**	7.709**	1719.881**
17	Q3 x Q7	-1.056	-1.181*	-1.093*	14.159**	22.196**	1.556**	0.807**	0.773**	4.536**	2027.082**
18	Q3 x Q8	-4.222**	-3.748**	-4.193**	-0.907	-3.804	-2.101**	0.680**	0.713*	-1.497*	-79.919
19	Q4 x Q5	0.011	-0.081	-2.959**	11.826**	16.163**	1.179**	0.613**	0.006	3.426**	625.048
20	Q4 x Q6	0.078	0.252	1.441**	0.059	5.430	2.426**	-0.387	0.206	-0.891	510.415*
21	Q4 x Q7	0.111	0.852	0.374	19.559**	19.630**	1.693**	1.380**	0.759**	6.736**	659.615**
22	Q4 x Q8	-2.722**	-3.048**	-2.393**	17.826**	-1.704	-0.197	0.987**	0.566*	2.536**	520.615*
23	Q5 x Q6	-3.956**	-3.681**	-4.526**	9.359*	6.030	1.326**	1.993**	2.366**	5.309**	-176.352
24	Q5 x Q7	3.078**	2.585**	1.407**	-39.474**	-26.437**	-1.774**	-0.207	0.253	-5.931**	-1243.485**
25	Q5 x Q8	2.578**	2.352**	2.307**	-23.207**	-18.770**	-1.264**	-1.267**	-1.941**	-7.797**	-1253.485**
26	Q6 x Q7	1.811**	1.585**	2.141**	-13.574**	-29.504**	-3.961**	-2.240**	-3.681**	-7.947**	-932.785**
27	Q6 x Q8	2.311**	2.685**	2.707**	-2.974	3.496	-0.317	-1.833**	-1.074**	-5.414**	-775.452**
28	Q7 x Q8	-0.656	0.000	-0.693	5.526	10.696**	-0.117	0.767**	0.413	6.479**	300.082
SE S(I,J)		0.533	0.459	0.521	4.312	3.284	0.314	0.215	0.280	0.725	242.449

*** Significant at 5% level of probability (p ≥0.05) ** Significant at 1% level of probability (p ≥0.01) * SE S (I, J) Standard Error for sca effects**

the cross Q1 X Q6 (3.25) performed best followed by the crosses Q3 X Q6 (2.55) and Q4 X Q6 (2.42). For CD also best performance was reported in the cross Q1 X Q6 (4.06) followed by Q5 X Q6 (1.99) and Q3 X Q6 (1.94). Three best crosses for NKRPC were Q5 X Q6 (2.36), Q3 X Q6 (2.219) and Q1 X Q6 (1.833) while for NGPR three best performance were found in the crosses Q3 X Q6 (7.70), Q1 X Q6 (7.39) and Q4 X Q7 (6.73). For GY the cross Q2 X Q8 (2106.748) showed highest significant positive sca effects followed by Q1 X Q6 (2053.04) and Q3 X Q7 (2027.08). Netravati *et al.* (2014), E1-

Shamarka *et al.* (2015), Patel *et al.* (2016), Sandesh *et al.* (2018), Arunkumar *et al.*, (2022) and Kamal *et al.* (2023) also found significant positive sca effects for grain yield and its component traits. Karim *et al.* (2018) observed non-significant sca effect for yield. Crosses showing high sca effects for grain yield have at least one parent with low gca effects. These crosses have potential to produce hybrids with high yielding capability.

Conclusion

It may be concluded that superior inbred lines which showed significant positive gca effects for grain yield and yield-attributing traits can be used as parents in breeding for improvement in yield and its attributing traits. They can also be utilized as a component line for development of synthetic and composite variety of maize. The superior crosses resulted from the crosses can be directly use as hybrid or can be improved further for other important agronomic traits. These crosses reflected that there is high amount of non-additive gene action present in the crosses so there is scope of exploitation of heterosis and biparental mating for improvement of yield and other important traits.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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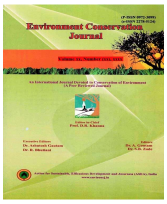

Pattern of litterfall production and nutrient addition in soil through litterfall by different tree species: A review

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ABSTRACT

Innutrient dynamics, an extremely valuable resource is litterfall. It is crucial to the dynamics of soil nutrients, the characteristics of soil, and the transfer of energy. In an agroforestry system, decomposition and litter fall are the two key processes that contribute to soil enrichment. In addition to affecting soil characteristics and ecology, litter fall in soil has a significant impact on carbon sequestration. The type of tree, the management methods, and the quantity and quality of litter all affect how much the soil is enriched. The complicated ecophysiological process of litterfall is influenced by both internal and external variables. Other significant causes of leaf fall include variations in weather and photoperiod as well as internal plant characteristics like age of leaf or potential endogenous rhythams. Nutrients are converted as a result of decomposition of different components of litter, and their release is influenced by the content of the litter, moisture, activity of microbes, C:N, temperature, and other variables. Litterfall therefore contributes to the long-term maintenance of nutrient levels in forest ecosystems and has been a primary research focus for a better understanding of soil fertility, site productivity, and forest services.

Introduction

Our capacity to meet food demands is threatened by the rapidly rising human population, the shrinking amount of cropland, and the declining fertility of the soil. In recent years, interest in sustainable farming practises like agroforestry has grown. Area under agroforestry is 25.32 million ha, or 8.2% of the total land area in India (Dhyani *et al.* 2013). Due to their short rotation, rapid growth, and high market value, certain tree species, including poplar (*Populus deltoides*) and eucalyptus (*Eucalyptus tereticornis*), are significant in agroforestry. So, these species have now been planted on degraded ground. In agricultural environments, the planting of specific tree species may reduce crop failure rates while also enhancing soil fertility (Chen *et al.,* 2019, Kumar *et al.,* 2017). By fixing nitrogen, absorbing nutrients from deeper soil layers, and producing and decomposing tree biomass, trees increase the fertility of the soil (Nair, 2011). Litter, leaf litter, or tree litter is any dead plant material that has fallen to the ground, including leaves, bark, needles, and twigs. Litter offers habitat to plants, microbes, and small animals. Nutrients are released into the ecosystem as litter breaks down. Humus is the fraction of the litter that takes longer to break down. The ecological stability of a wooded ecosystem depends fundamentally on the presence of leaf litter. For the majority of terrestrial ecosystems, the amount and pattern of litterfall influences the cycling of nutrient, the fertility of the soil, and primary production because leaf litter serves as a crucial link between vegetation and soils

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and enables nutrients to be returned to the soils. (Fontes *et al.,* 2014, Becker *et al.,* 2015). Additionally, root extension and crown expansion aid in the topsoil's organic matter buildup, which enhances the soil's qualities in the root zone (Mukhopadhyay *et al.,* 2016). The cycling of carbon and nutrients are among the main biological processes that are enabled by the breaking down of plant litter. (Cornwell *et al.,* 2008). Besides this, litter production is reliant on the structural features of the vegetation, such as tree number, dimensions, and diversity of species which offers valuable insight into how an ecosystem functions, specifically in relation to the incorporation of soil organic carbon, the dynamics of decomposition, and the cycling of nutrients (Argao *et al.,* 2009). Litterfall accounts for an estimated 5% (43 Pg C) of the total worldwide forest carbon pool, transferring around one-third of the yearly carbon intake to the soil surface (Leitner *et al.,* 2016, Neumann *et al.,* 2018, Pan *et al.,* 2011). The Intergovernmental Panel on Climate Change (IPCC) lists litter carbon as being one of the five carbon pools in ecosystems of forests, in addition to aboveground biomass, belowground biomass, dead wood, and organic soil, in the yearly national greenhouse gas (GHG) inventories. (Eggleston *et al.,* 2006). Abiotic and biotic factors such as geographic location (e.g., latitude, longitude, and altitude), climate conditions (e.g., temperature and precipitation), and the structure of the vegetation (e.g., forest category, stand age, species, density, height, and diameter at breast height) all impacts litterfall production. (Starr *et al*., 2005, Chave *et al.,* 2010, Guo *et al.,* 2019, Kirman *et al.,* 2007, Quadros, 2019). According to earlier research (Martinez-Alonso *et al.,* 2007, Zhang *et al.,* 2014, Bhatti and Jassal, 2015), whereas climate-related characteristics, particularly temperature and precipitation, are the main drivers of litterfall generation, their consequences vary among regions and forest types. A common nondestructive method of determining the dynamics of airborne biomass is litterfall collecting. A significant source of nitrogen flow to soil is the production of leaf material. Important processes for transferring carbon and other nutrients from the above-ground system to the below-ground system in forests include litterfall and its subsequent decomposition. Through the transformation of organic components into inorganic elements that the plants can re-absorb, these activities represent important steps in the cycling of nutrients. Climate factors including temperature and precipitation as well as different forest types have been reported to have an impact on litter quality in terms of nitrogen, phosphorus, and potassium concentration. Different tree species produce litterfall and release nutrients in different ways. Additionally, litterfall alters the soil's physical and chemical characteristics, microbial activity, and variety of the soil's fauna and flora through the addition of organic matter and nutrients. Litterfall therefore contributes to the long-term maintenance of nutrient levels in forest ecosystems and has been a primary research focus for a better understanding of soil fertility, site productivity, and forest services.Only 2.86 percent of known forests were present in the primarily agricultural state of Haryana at the time of its founding. Agroforestry in the state at the time consisted of a few naturally occurring trees on agricultural bunds, including *Prosopis cineraria*, *Eucalyptus tereticor*, *Dalbergia sissoo*, *Populus deltoids*, *Acacia nilotica*, and *Azadirachta indica* (Chaturvedi *et al.,* 2016). These trees offer shade to agricultural workers and bullocks/camels as well as insurance security during drought years and crop failures. The introduction of poplar through WIMCO-NABARD partnerships with a buy-back guarantee during the 1980s transformed Haryana for the development of agroforestry. Poplar's success in Haryana became the world's best example of commercial agroforestry. Since then, it has grown in significance and has extended to new regions of Haryana. The areas covered by agroforestry have grown even more after the introduction of clonal eucalyptus, *Melia* and *Ailanthus excelsa*. According to Giri *et al.* (2019), poplar-based agroforestry systems are a sustainable method of using land in northern India since they increase biomass, soil fertility, carbon content, and other ecosystem services. Due to its rapid growth pattern and rising demand in the pulp and paper industry, *Melia composite* is a viable agroforestry tree species for boundary and block plantations. It grows well with up to 4 dS/m of EC and well-drained soils with moderate soil fertility.

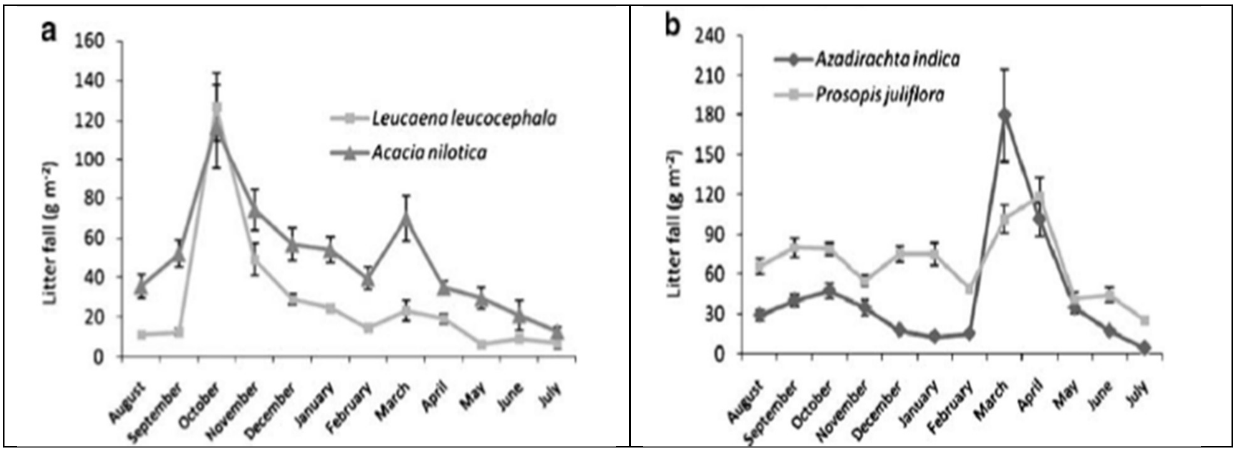

Figure 1: Leaf litterfall pattern of the four forest tree species (Jha and Mohapatra, 2010)

Effect of environmental variables on litter production

In areas with and without a dry season the dry and wet seasons are when litterfall in stands is at its highest, respectively. Litterfall output in ecosystems is highly correlated with rainfall seasonality (Becker *et al.,* 2015, Owusu-Sekyere *et al.,* 2006, Muoghalu and Odiwe, 2011). In particular, low air humidity, high temperature, and their interplay reduce litterfall by promoting the generation of abscisic acid in cocoa agroforestry systems (Dawoe *et al.,* 2010, Yang *et al.,* 2003, Triadiati *et al.,* 2011). Elevation, wind, and foliar diseases can all have an impact on leaf litterfall (Mamani-Pati *et al.,* 2012, Becker *et al.,* 2015). According to Kumar 2008, Domnguez *et al.* 2014, Muoghalu and Odiwe 2011, soil quality and management affect the quantity and the kind of the litter produced by an ecosystem. Because of faster biomass accumulation and/or a lower rate of nutrient absorption from litter before abscission, stands on fertile soils produce more high-quality litter than stands on poor soils (Kumar 2008, Fontes *et al.,* 2014). According to Wood *et al.* 2007, the quantity of litterfall, the quality of the leaf litter, the velocity of decomposition, and nitrogen mineralization are all factors that affect soil fertility. Because plants in natural systems, like forests, primarily rely on nutrient cycling to meet their nutritional needs, species variety and composition, as well as moisture availability, are used to control supply rate of nutrient and limitation of nutrient (Kumar 2008, Becker *et al.,* 2015, Wood *et al.,* 2007).

Effect of environmental variables on litter dynamics

There are three main ways that decomposition take place, (1) breaking down of litter in smaller fragments; (2) the dissolution of substances that are soluble in the soil; (3) the breakdown by decomposer organisms (Hattenschwiler and Jorgensen, 2010; Giebelmann *et al.* 2013).The environment, climate, and soil characteristics such as the soil's chemical makeup and physical structure, which indirectly regulates temperature and humidity, all have an impact on how quickly leaf litter decomposes in the soil (Rawat and Nautiyal 2009, Aravena *et al.,* 2002). For instance, due to the increased microbial decomposer populations and the microclimatic circumstances that support stand-specific litter decomposition, the amount of litter decomposition is greatly impacted by the organic forest top soil (Hayes and Holl, 2003). The rate of decomposition of litter is also greatly influenced by the soil's pH, temperature, and NH_4-N content. Temperature, moisture, and other microclimate elements may also have an impact on the breakdown rate of litter. Several publications claim that the process of decomposition of litter was sluggish in the cold and quick when it rained (Tripathi *et al.,* 2009, Devis and Yadav 2007), and the main causes for the faster litter decomposition rate during the rainy season may be the presence of sufficient rainfall, suitable moisture, and higher micro-fungal populations. Due to heavy rainfall, moist soil, and a high microbial load. Kumar *et al.* 2010, also came to the same conclusion that there is a high rate of litter

Table 1: Chemical characteristics of the litter of the different tree species (Verma *et al.,* 2022)

Parameter	N(%)	P (%)	K (%)	Ca (%)	Mg (%)	Cellulose (%)	Lignin (%)	Carbon (%)	C:N	L:N	C:P	N:P
Propsopis cineraria	2.21a	0.24a	0.71a	2.28a	0.58b	20.38b	11.68b	43.17ab	19.66b	5.33c	177.19a	9.04a
Hardwickia binata	1.41b	0.21a	0.56a	1.99a	0.67ab	25.81a	13.88a	43.85a	32.82a	13.88a	212.87a	6.58b
Tecomella undulata	2.31a	0.25a	0.51a	1.13b	0.98a	11.20c	9.30c	42.07b	19.91b	9.30b	172.40a	8.62a

decomposition and an increase in weight loss in rainy seasons. Even though this assertion should be evident, there is ongoing discussion regarding which climate index may most accurately forecast degradation rates. A number of scholars (including Magid *et al.,* 2002, Joffre *et al.,* 2001) strongly criticize this idea and claim that the correlation between real evapotranspiration and litter decomposition does not offer accurate indicators of decay rates. Furthermore, litter decomposes more quickly than its original location than any other plant cover environment (Chapman and Koch, 2007). For instance, conifer habitat decomposes more slowly than broadleaved habitat (Aravena *et al.,* 2002, Rawat and Nautiyal, 2009). When compared to higher altitudes, litter decomposes more quickly at lower elevations depending on the type of vegetation there (Veen *et al.,* 2015). Additionally, soil N concentration, soil organic matter content, fungal, bacterial ratio soil C:N and C:P all lowered the rate of litter breakdown (Veen *et al.,* 2015, Parsons *et al.,* 2014).

Importance of litterfall production

In agroforestry systems, decomposition of litter and litterfall are important nutrient recycling vectors. Woody perennials produce litter that enriches the soil with nutrients and gives decomposers the ingredients they need to reduce complex dead organic matter to simple mineral forms. These agroforestry activities contribute nutrients to the soil, replenishing its fertility (Notaro *et al.,* 2014, Yadav *et al.,* 2008). The rate of litter breakdown is influenced by the relationship between the soil biota, variations in the climate and litter quality. Age and species variations, site features, seasonal fluctuations, and tree management practices, as well as tree base area and stand age are some of the factors that determine litterfall rates (Kumar, 2008). The practical understanding of the consequences of litter is well established in many traditional agricultural methods. Plant litters have been used for a variety of things, such as mulching in low-tech agriculture, gardening, and modern horticulture (Gartner and Cardon, 2006), protecting against weed infestation (Cornwell *et al.,* 2008), preventing soil freezing and soil erosion (Cornwell *et al.,* 2008), improving mine reclamation (Giebelmann *et al.,* 2013), preserving moisture and reducing evapotranspiration, and enhancing the function of the forest ecosystem (Cornwell *et al.,* 2008). In forest ecosystems, nitrogen cycling directly influences productivity by making nutrients available for plant development (Krishna and Mohan, 2007). Primary production is typically assessed by the creation of litter, which serves as the primary source of soil organic carbon (SOC) and the cycling of plant nutrients. In the forest ecosystem, litter is another measure of primary production in addition to tree heights and diameters.

Temporal litterfall production by different tree species

Under semi-arid conditions of Haryana, Bhardwaj *et al.* 2016 studied the effect of tree (5*4, 10*2 and 18*2*2 m) different trees spacing on litterfall production in popular based agroforestry system and observed that litterfall under 5*4 m spacing was significantly higher by 2.48 and 1.84 times as compared to 10*2 and 18*2*2 m, respectively.

For three important agroforestry tree species growing in the dry western region of India, *Prosopis cineraria*, *Tecomella undulata* and *Hardwickia binata*, Verma *et al.* 2022 investigated litterfall production, decomposition, and nutrient release. *H. binata* (9.44 Mg/ha/yr) exhibited the highest litterfall, being followed by *P. cineraria* (8.94 Mg/h/yr) and *T. undulata* (3.74 Mg/h/yr). *P. cineraria*, *T. undulata*, and *H. binata* are the plants that drop their leaves most frequently in the winter and summer, respectively.

In Zambia, Yengwe *et al.* (2018) estimate *Faidherbia* tree litterfall patterns and nutrient deposition from various age classes. From 8-, 15-, and 22-year-old trees, the average amount of leaf litterfall was 1.6, 1.7, and 3.8 t DM/h, respectively. With this amount of litterfall, there might be an annual carbon and nutrient deposition of 0.7-1.6 t C/h, 34-83 kg N/h, 1.8-4.3 kg P/h, and 10-26 kg K/h. Compared to litterfall from 8- and 22-year-old trees, litterfall from 15-year-old trees exhibited higher concentrations of P and K. When compared to litterfall from 8- and 15-year-old trees, the C/N ratio of 22-year-old trees' litter was intermediate.

Negash and Starr (2021) investigated the decomposition of six different tree species litter in response to inputs of litterfall carbon on native agroforestry farms in southern Ethiopia. They noted that, aside from C and Mg concentrations, there were notable variations in the chemical composition of the litterfall (original litter material) across the species. In comparison to the other species, *C. macrostachyus*, *E. brucei* and *M. ferruginea* showed higher N concentrations and lower C/N ratios. The greatest Ca concentrations were also found in *C. macrostachyus* and *E. brucei*, however the difference between them and other species was not considerable. The lowest K concentrations were found in *M. indica* and *P. americana*, with a notable divergence from other species. The amount of magnesium did not considerably vary amongst the species.

In semi-arid regions of western Rajasthan, Yadav *et al.* (2008) reported significant seasonal variation in the litter production by various multipurpose trees. A significant pulse of litter production correlated with the winter months (November-February), and a period of decreased litterfall with the rainy season (July-October). In the Taran Taran district of Punjab, Rani *et al.* (2016) evaluated the litterfall production patterns of various tree species. They came to the conclusion that *P. deltoides* produced the highest amount of leaf litter (7.8 t/h), followed by *T. grandis* (1.83 t/h), and *E. tereticornis* (1.77 t/h), while *P. pyrifolia* produced the least (0.34 t/h).

Jha and Mohapatra (2010) investigated leaf litterfall in four prominent tree species from India's semi-arid region: *Leucaena leucocephala*, *Acacia nilotica*, *Azadirachta indica* and *Prosopis juliflora*. They demonstrated that all four species showed distinct seasonal swings but a yearly trend in leaf litterfall with a unimodal peak. *Leucaena leucocephala* and *Acacia nilotica* had leaf litterfall that varied from 6.5 (June) to 126.7 g/m^2 (October) and 12.8 (June) to 116.7 g/m^2 (October), respectively. *Azadirachta indica* and *Prosopis juliflora* had mean monthly leaf litterfalls of 4.5 (July) - 179.9 g/m^2 (March) and 25.8 (July) - 118.8 g/m^2 (April), respectively (Fig. 1). The amount of leaf litterfall varied greatly among the different forest species. Prosopis had much more leaf litter fall compared to other forest species being studied. Total leaf litterfall weight varied from 5.98, 5.38, and 3.31 Mg/ha/yr under *Acacia nilotica*, *Azadirachta indica* and *Leucaena leucocephala*, respectively, to as high as 8.13 Mg/ha/y in *Prosopis juliflora*. According to some writers fluctuations in temperature and photoperiod as well as within-plant characteristics like leaf age or potential endogenous rhythms are also significant causes of leaf fall. Given that all the species were of comparable age, the amount of leaf litterfall is closely related to canopy development, which is controlled by species nature (Carrera *et al.,* 2008).

Devi *et al.* (2021) investigated the pattern and overall litterfall production in eucalyptus-based agroforestry systems. They divided the litter into three categories: leaves, woody items, and other items. In the Kinnow + Eucalyptus + wheat system, the Eucalyptus tree supplied the most leaf litter (6.82 t/ha/annum), followed by the Kinnow tree (2.61 t/ha/annum), and the Kinnow tree (0.434 t/ha/annum) in the Kinnow + Wheat system. It was found that the months of November and December provided the most leaf litter, while May and June showed the least amount of litterfall.

The production of litterfall in the *Eucalyptus dunnii* Maiden stand was examined by Ludvichak *et al.* (2016). Leaf litter accounted for 61.57% of the overall litterfall production, which was 6.99 Mg/h/y. In comparison to the other litter components, such as twigs, thick branches, and miscellaneous, leaf litter had a higher nutritious content. Leaves, twigs, thick branches, and miscellaneous made up 61.57, 17.34, 13.83, and 7.26% of the total litterfall measured, respectively.

In a study, Kumar *et al.* (2017) observed that plantations of Prosopis cineraria, *Acacia senegal* and *Tecomella undulata* produced litter at rates of 16.1, 2.8, and 1.0 t/h, respectively. While *T. undulata* had the highest quantities of K, Fe, and Zn and P. cineraria had the highest amounts of Cu, *A. senegal* leaf litter had the highest concentrations of

P, Ca, Mg, & Mn. However, *P. cineraria* and *T. undulata* had higher and lower nutritional returns, respectively. Under all tree plantations, the sequence of nutrient return to soil was Ca > K > Mg > P > Fe > Mn > Zn > Cu.

Nutrient addition/release by different tree species

Satyawali *et al.* (2017) studied the monthly nutrient return via litterfall of *Eucalyptus camaldulensis* and *Melia azedarach* plantation in soil at different high density spacings. Maximum and minimum return of available macronutrients (kg/h) in soil was found in the months of March-April (5.58-6.10 N, 0.42-0.46 P, 1.64-1.79 K) and December-January (1.251.03 N, 0.10-0.08 P, 0.37-0.30 K) for *Eucalyptus camaldulensis* and December-January (7.148.81 N, 1.44-1.78 P, 5.19-6.41 K) and March-April (0.69-1.19 N, 0.14-0.24 P, 0.50-0.87 K) for *Melia azedarach*, respectively. The available NPK was found to be decreasing with the successive soil depths under all spacings and decreasing trend with the increase in planting density was observed which might be due to higher uptake of nutrients by more trees per unit area. Devi *et al.* (2021) examined the nutrient dynamics related to litterfall in the semi-arid region of Haryana. They noticed an increase in N, P and K concentrations due to tree species' leaf litter fall, and these nutrients' release into the soil as a result of their decomposition is a primary cause of the soil's improved N, P and K content. When compared to Kinnow leaf litter fall, the addition of N (94.1 kg/h) and P (19.1 kg/h) was substantially higher from Eucalyptus leaf litter fall; however, the addition of K (26.6 kg/h) was significantly higher from Kinnow litter fall (12.3 kg/h). Under alkaline soils of Haryana, Bhardwaj *et al.* (2016) analysed the nutrient concentration of macronutrients of litterfall from different spacing of 8 year old poplar based agroforestry systems. They revealed that there was no significant differences in the content of nitrogen, phosphorus and potassium in the leaves litterfall. Although, the content of nitrogen and phosphorus (1.32 and 0.15%) was highest in 5*4 m spacing whereas, Potassium content (0.64%) was highest under 18*2*2 m spacing.

Singh (2009) evaluated the poplar's nutrient concentrations in an agroforestry system under subtropical conditions at various ages and discovered that the concentrations of N, P, K, Ca, and S considerably reduced as plantation ages increased. Nutrient concentration was highest in plants that were one year old and lowest in those that were six years old. The dilution effect may be responsible for the decline in nutrient concentration with age. The concentration of Ca was highest (1.77-2.12%) and that of P was lowest (0.09-0.16%) among the major nutrients at different ages. In poplar plantations with three spacings and two row directions, Singh *et al.* (2007) also found the highest concentration of calcium and the lowest concentration of phosphorus among the macronutrients. While litterfall was lowest (0.3 Mg/h) and highest (5.94 Mg/h) in plantations older than six years, respectively.

Yan *et al.* (2016) compared the nutrient concentration of senesced leaves of larch plantations and the secondary forest mainly dominated by *Quercus mongolica*, *Acer mono, Juglans mandshurica* and *Fraxinus rhynchophylla* plantations and reported significantly higher nutrient concentrations in *J. mandshurica* leaves among secondary forest plantations and lowest in *Larix spp*. The highest N, P, K, Ca, Cu, Zn concentration was recorded in *J. mandshurica* and Mg was in *A. mono* whereas lowest N, Ca, Mg, Cu was observed in *Larix* spp. and P, Zn was in *Q. mongolica*. Rani *et al.* (2016) evaluated the addition of nutrients by four distinct species and found that nitrogen (2.27%), potassium (1.90%), and phosphorous (0.32%) contributed the most nutrients through litter fall. *P. deltoides* (2.27%) and *P. pyrifolia* (1.15%) had the highest and lowest N input through leaf litter, respectively. K input (%) was highest in *T. grandis* leaves (0.32) and lowest in *E. tereticornis* (0.21). *P. deltoides* had the highest P input (%) through leaf litter (1.90), whereas *E. tereticornis* had the lowest (1.27).

According to Yadav and Bisht (2014), total annual deposition of litterfall under agri-horticultural systems was determined to be 2143.3 kg/h/yr, and the relative richness of nutrients in pecan nut tree litter fall was in the order of C>N>K>P. The total nutrient accumulation from the aforementioned pecan nut litter fall might be 901.91 kg of carbon per hectare per year, 57.44 kg N/h/y, 3.21 kg of phosphorus per hectare per year, and 43.29 kg of K/h/y. In the agri-horticultural systems, there was a large buildup of soil organic carbon and accessible NPK.

The concentration of N in the leaves was significantly different (p 0.05) between the species in the western arid region of India, according to Verma *et al.* (2022) and followed the order *T. undulata* > *P. cineraria* > *H. binata*, while the concentrations of P and K were not statistically different among the species. *P. cineraria* and *T. undulata* had the highest calcium and magnesium concentrations, respectively. The highest concentrations of cellulose, lignin, and carbon were found in the leaves of *H. binata*, followed by *P. cineraria*, while the lowest concentrations were found in *T. undulata*.
Between species, there were large differences in the C:N ratios, which ranged from 19.66 to 32.82. Although the differences in the C:P ratios amongst the species were not statistically significant, *H. binata* had the greatest C:P ratio (more than 200:1), followed by *P. cineraria*, and *T. undulata*. According to Table 1, the initial L:N and N:P ratios varied greatly among the various litter types, ranging from 5.33 to 13.88 for L:N and 6.58 to 9.04 for N,P. The traditional Eucalyptus-based agroforestry system's showed nutrient budget at various spacings was published by Kumar *et al.* (2021). They came to the conclusion that the leaves and branches were the main nutrient source. While in 2014–15, 61.5 m spacing, 33 m spacing, and 171 m spacing all yielded higher amounts of nitrogen (N) through leaf litter (54.04 and 53.05 kg/h, respectively). Out of which, the intercrops utilized a total of 44.01 kg/ha of nitrogen, 9.96 kg/h of phosphorus, and 68.65 kg/ha of potassium, respectively. Consequently, there are still 7.05 (kg/h) of phosphorus and 45.31 (kg/h) of nitrogen.
The recovery of nutrients by litterfall in a stand of *Eucalyptus dunnii* in a Pampa ecosystem is evaluated by Ludvichak *et al.* (2016) and concluded that the order of macro- and micro-nutrient concentration of leaf litter varied as Ca (12.52 g/kg) > N (7.76 g/kg) > K (3.77 g/kg) > Mg (2.43 g/kg)> S (0.78 g/kg)> P (0.52 g/kg) and Mn (1252.73 ppm) > Fe (106.52 ppm) > B (40.99 ppm) > Zn (12.44 ppm) > Cu (5.46 ppm) respectively. The same pattern was observed for nutrient return through litterfall.

Conclusion

The primary mechanism responsible for soil improvement in agroforestry systems is litterfall from trees. The growth pattern, age, density and canopy characteristics, as well as the environment, including temperature, all affect the quantity and quality of litterfall. The type of tree, the management techniques used, and the quantity and quality of litter all affect how much nutrient return (macro and micro nutrients) occurs in the soil. In order to research how different tree species affect soil enrichment, it is essential to obtain knowledge of the litterfall, nutrient content and prospective nutrient returns by different tree species.

Conflict of interest

The authors declare that they have no conflict of interest.

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Methods for eliminating micropollutant from wastewater: A review

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ABSTRACT

The amount of suspended solid and medicinal micropollutants, such as fungicides, personal care products, contraceptive medications, antibiotics and aromatic hydrocarbons are increasing daily and has reached an alarming level. The micropollutant present in wastewater must be treated before its release because it forms adverse effect on mortal health. Because some harmful micropollutants are incredibly difficult to remove from WWTPs because of their nonbiodegradability, poor adsorption capability, complex nature and traditional wastewater treatments are precious or insufficient for decontamination. For the micropollutant declination some of the conventional physicochemical has been used. The use of powdered activated carbon (PAC) for water purification has been proven to be effective without harming the environment. Advanced oxidation technologies (AOTs), typically applied after natural processes have recently emerged as effective tertiary treatments for the withdrawal of micropollutants at high concentrations. Various methods have been developed and studied for the removal of these micropollutants from wastewater. This review aims to provide a comprehensive overview of the different methods employed, including physical, chemical, and biological processes, highlighting their effectiveness and limitations in micropollutant removal. As well as improving treatment efficiency, they can also remove any accumulation of dangerous byproducts produced during treatment.

Introduction

All living creatures need water to survive, and water availability is associated with major causes of mortality, such as domestic use and agriculture. Some contaminants of emerging concern (CECs) from different sources end up in aquatic resources, including ground water, surface water and drinking water, at concentrations ranging from a few nanograms/liter to a few milligrams/liter (Barbosa *et al.,* 2016; Bhutiani *et al.,* 2022; Ahamad *et al.,* 2023). Domestic, agricultural, sanitarium and industrial wastewater; livestock; and aquaculture are among the anthropogenic sources of MPs (Barbosa *et al.,* 2015; Bhutiani *et al.,* 2021). Urban wastewater treatment plants (UWWTPs) release treated backwaters as a significant source of MPs, and conventional physicochemical and biological treatment methods are not designed to eliminate organic composites completely from trace concentrations (Barbosa *et al.,* 2015; Bhutiani and Ahamad, 2018; Sousa *et al.,* 2018). The severe biological effects of these micropollutants have led to years of research on these pollutants (Aschermann *et al.,* 2018; Batel *et al.,* 2020; Gautam *et al.,* 2020). The amount of organic micropollutants, such as fungicides, personal care products, contraceptive medications, antibiotics and aromatic hydrocarbons, is increasing daily and has reached an alarming level (Mailler *et al.,* 2016; Meza *et al.,* 2020). Some harmful micropollutants are incredibly difficult to remove from WWTPs because of their nonbiodegradability, poor adsorption capability, complex nature and traditional wastewater

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treatments, which are valuable or insufficient for decontamination (Benstoem *et al.,* 2017; Chau *et al.,* 2018). The majority of the review studies focused on physicochemical techniques for micropollutant elimination. The biological treatment of micropollutants, which is increasingly important due to its various advantages, such as low cost, simple design and high removal effectiveness, when compared to conventional treatment methods, is still the subject of relatively few reviews. Therefore, the purpose of this research is to review the knowledge gaps that exist today about the various biological treatment procedures that are employed to remove micropollutants from wastewater. Similarly, new biological remedy structures, such as immobilized bioreactors, moving bed biofilm bioreactor systems and two-section partitioning biorreactors, have not been reviewed in advance. AOTs can be applied to distinctly toxic water effluent as a preremedy to decrease toxins and increase the biodegradability of the water. The installation of additional AOT devices after secondary biological treatment has attracted great interest in the water industry, as similar processes have been attributed to the removal of multiple MPs from UWWTP streams. PAC recycling with coagulant ($FeCl_3$) has been used in the past for wastewater treatment, but there is no literature on the interaction of coagulant (FeCl3) with flocculants for water hardness. To the best of our understanding, the PAC recirculation process, biological treatment process and advanced oxidation technology have been used for the removal of micropollutants. Thus, this research also fills these research gaps by providing a suitable, flexible, simple and usable method for wastewater treatment.

Sources of organic micro pollutants

Medical facility effluents, industrial wastewater, medical facility backwater, runoff from concentrated animal feeding operations, agricultural runoff, etc., are the main sources of micropollutants in the environment. Micropollutant pollution of the environment is largely the result of pharmaceutical, large-scale pesticide and other chemical industry waste water production. One of the main sources of micropollutants is runoff from farmland and best-parenting areas, notably in the case of fungicides used to boost productivity as well as antibiotics and hormonal steroids used for best conservation (Song *et al.,* 2007). Industrial waste streams, septic tanks, sewage treatment facilities and leakage from landfills are the other sources of micropollutants (Matthiessen *et al.,* 2006). In addition to pharmaceuticals (NSAIDs, anticonvulsants, lipid regulators, antibiotics, stimulants, and blockers), personal care products (UV filters, fragrances, insect repellents, and disinfectants), and steroid hormones (estrogens), domestic wastewater is a major source of many micropollutants (Luo *et al.,* 2014). Both ecology and human health are adversely affected by micropollutants, although micropollutants cannot be arranged in the same order based on their package. Pruden *et al.* (2006) discussed the impacts of micropollutant exposure, which includes both short- and long-term toxic and endocrine-dismembering effects.

Effect of micropollutants

At certain boluses, a number of substances interfere with the endocrine system, producing malignant excrescence and other birth defects in energized infants. There have been reports of other health problems related to an implied hazard from micropollutants, such as anomalies in children and babies, bone cancer, diabetes/metabolic syndrome, and reproductive failure. Certain germs that are frequently exposed to the same toxins also become resistant to antibiotics, increasing the difficulty of treatment. Long-term displays may also result in ecosystem bioaccumulation (Choi *et al.,* 2016). Therefore, the presence of micropollutants in the environment has been established to have a detrimental effect on the health of all living things. Therefore, micropollutants in landscape pollutants negatively affect the health of all living organisms. The negative health effects of these micropollutants necessitate the use of technologies that help facilitate their release into the environment, including physicochemical processes, such as advanced oxidation techniques, membrane-based processes, adsorption and biological processes, using various bioreactors.

Removal of organic micropollutants from wastewater

By incorporating advanced and creative treatment technologies into WWTP design, micropollutants can be converted into composites that are less harmful or even nonharmful. Activated carbon powder (PAC), membrane separators (MSSTs), and advanced oxidation technologies (AOTs) are all innovative water treatment processes (Sudhakaran *et al.,* 2013). In the literature, several bacterial and fungal species are described as generating micropollutants (Murínová *et al.,* 2014; Barbosa *et al.,* 2016; Bhutiani *et al.,* 2016; Ahmed *et al.,* 2017). A decrease in micropollutants by microbes is accompanied by catabolic activity, during which micropollutants become substrates for growth (Tran *et al.,* 2013). Micropollutants can be efficiently degraded using oxidizing chemical agents, such as chlorine, hydrogen peroxide, and ozone, along with a mixture of transition metals and advanced oxidation processes (AOPs) based on metal oxide-based catalysts.

Powdered activated carbon (PAC)

As a powder or granule produced with a surface prolixity of less than 1 mm, activated carbons are capable of diffusing into or onto their surfaces easily. PAC is made from pretreated or crushed carbon particles, which are also added directly to process units such as gravity filters, cleanses, high-speed mixers and dewatering ports. Two types of PACs, Norit SAE-Super (Norit) and Donau Carbon Carbopal AP (Donau), were used for all the experiments; these materials were made from different starting materials and produced by different manufacturers. The resulting products differed in terms of particle size distribution, specific pore volume, and skeletal density. The PAC particle size plays an important role in the removal of micropollutants from wastewater either by precipitation or sedimentation. Therefore, measuring the particle size distribution is critical. This is why Norit is larger than Donaus. Dose effects were estimated with varying dose concentrations of PAC in wastewater ranging from 10 to 40 mg/l. In wastewater treatment (WWT), two different kinds of PACs (Norit and Donau) were tested, and the results were compared on the basis of performance. After a certain range, the PAC can begin to donate to solid components of the wastewater, which then begin to participate in adsorption in the active zones together with the suspended solids. As a result, negative analogous outcomes were determined based on the above research (Boehler *et al.,* 2012 and Guillossou *et al.,* 2020). Particles may coalesce or coalesce as the PAC dose increases, leaving fewer active sites for adsorption (Noreen *et al.,* 2020). In terms of particle size, diameter, formation material and bone density, Donaul has slightly different characteristics from Norit. It is obvious that the Donu withdrawal efficiency was relatively lower than that of Norit for all the samples. A smaller number of coarser and finer particles produced a smaller adsorption amount. Additionally, the lower specific pore volume (cm^3/gm) promoted the more efficient performance of Norit on its surface than on the other surfaces because small draped micropollutants (MPs) are wrapped in the pores of the Norit surface and cannot be released. Laboratory experiments, performed mainly with PAC, provided a comprehensive understanding of the adsorption mechanisms, which were also expressed in previous studies (Karelid *et al.,* 2017a). This lower quantity of adsorbed material on Donau Island was due to differences in the production material, size, internal structure, etc.

Physicochemical treatment processes

Several physicochemical processes have been estimated for the removal of micropollutants through water and wastewater. The potency of physicochemical techniques relies on functional conditions, material composites and the type of wastewater (Bhutiani *et al.,* 2017). Membrane filters are commonly used to remove microorganisms and salt from wastewater and surface water; however, their use for the removal of micropollutants has recently been demonstrated in the literature. Commonly used membrane techniques incorporate high-pressure and low-pressure grade systems. Microfiltration (MF) and ultrafiltration are low-pressure grade systems used at pressures ranging from 5 bar to 10 bar, while reverse osmosis (RO), high-pressure RO and nanofiltration (NF) are low-pressure grade systems that operate at pressures ranging from 50 bars to 150 bars. Among these systems, a high-pressure grade system is more appropriate for removing organic micropollutants (MPs) (Coday *et al.,* 2014). Adsorption onto membranes, charge repulsion mechanisms and size exclusion generally occur during micropollutant retention through membranes. The molecular weight cutoff, specific physicochemical study, membrane fouling, process type and micropollutant working conditions all have significant impacts on the efficiency of the retention mechanism. Membrane fouling as a result of the deposition of particles and colloidal particles in the affluent is the primary drawback of the filtration process (Villegas *et al.,* 2016). The first expense of membrane-grounded innovation is likewise high. Although membrane-based technologies can destroy the filtrate in evaporation ponds, direct release of the filtrate into the environment poses a risk to ecosystems (Umar *et al.,* 2015). The most common method for removing micropollutants from wastewater is sorption, which mimics the physicochemical properties of sorbents (e.g., polarity, surface properties) and micropollutants (e.g., pKa, polarity, molecular weight). Adsorption and absorption involved in the sorption process of micropollutants. One of the major drawbacks of the adsorption process is the production of harmful sludge containing microputants; if this material is not disposed of properly, it can accidentally enter the environment (Justo *et al.,* 2015). In the 1980s, AOPs for the treatment of drinkable water that use multiple oxidizing species similar to sulfate or hydroxyl radicals were proposed for the first time. Additionally, it is currently being extensively utilized to treat a variety of types of wastewater, including sewage, industrial wastewater, and medical wastewater. Strong oxidants can degrade a variety of organic pollutants (Deng *et al.,* 2015). AOP can be used before or after a natural treatment process because it can degrade any carbon-containing micropollutants. AOP is similar to electro-Fenton processes; Fenton and photoFenton processes; electrochemical oxidation processes; wet peroxide/air oxidation in the presence of a catalyst; ozonation (catalytic); heterogeneous photocatalysis; and amalgamation of AOPs because standard oxidative processes ($KMnO_4$, H_2O_2, ClO_2, Cl_2, etc.) are inefficient (Ribeiro *et al.,* 2015). High operational costs, high energy consumption and the production of poisonous byproducts are the primary drawbacks of catalytic processes. Additionally, a variety of radical-scavenging compounds found in wastewater can harm these processes. Biological treatment systems have been prioritized as a means of overcoming the drawbacks of physical-chemical methods for the removal of micropollutants. They have been shown to be the most environmentally friendly, low cost and long-lasting, making them ideal for meeting environmental standards in developing nations.

Biological treatment process

Micropollutants are degraded by numerous species of bacteria and fungi, as reported in the literature. Micropollutant degradation by microbes is linked to the catabolic activity of microbes, and during this process, micropollutants are ingested as growth substrates (Tran *et al.,* 2013). Pollutant degradation is indirectly impacted by microbial growth on micropollutants and is dependent on many operational variables, such as light requirements, pH, extreme temperature, doubling time and agitation. Pollutant characteristics, including water solubility, surface characteristics, and charge, are crucial elements that affect treatment effectiveness. It has been widely reported that bacteria-based microorganisms can digest a variety of microputants. Pseudomonas sp. bacteria, for instance, are known to oxidize a variety of micropollutants. DCF was metabolically oxidized by *Pseudomonas putida* during active manganese oxidation. Few fungi produce extracellular enzymes that are very productive at degrading a variety of endocrine-disrupting chemicals (EDCs) despite their low substrate specificity. When phenolic chemicals are present, the lactase enzyme oxidizes them (Wong *et al.,* 2009). It was claimed that the enzyme acetate kinase can breakdown micropollutants such as bisphenol, galaxolide, nonylphenol, naproxen, and diclofenac when anaerobic conditions are present (Gonzalez-Gil *et al.,* 2017). To determine the role and method of action of a methanogenic enzyme described in this overall study's anaerobic breakdown of such micropollutants, additional research is necessary.

Advance oxidation technology –

According to the research of Garcia-Fernandez *et al.* (2018) and Garcia-Fernandez *et al.* (2015), the composition of the water matrix has a substantial impact on the inactivation of bacteria during water disinfection processes. Moreover, scavengers in the water matrix may hinder the removal of dissolved organic matter (DOM), which constitutes the majority of the organic matter in biologically treated urban wastewater. The location, time of year, operational conditions (pH, temperature, flow, etc.), and wastewater sources (industrial, home, agricultural, etc.) all affect the DOM composition. Fully characterizing the structural and functional complexity of DOM has become challenging. Because it can be evaluated broadly and lacks structural information, dissolved organic carbon (DOC) is typically utilized as a proxy variable for its quantification (Michael Kordatou *et al.,* 2015). The biological characteristics and environmental impact of DOM may change as a result of its transformation and byproduct creation during WWTP procedures, but our understanding of this process is currently limited. The most recent research on this topic described DOM in terms of its MW distribution, optical characteristics, and hydrophobicity (Wang *et al.,* 2018). DOM chemistry and reactivity have been characterized using many analytical methods, including spectroscopic chromatography, physicochemical analyses, thermal degradation methods and other fractionation procedures. The components of wastewater include a variety of organics (e.g., carbohydrates, proteins, fulvic acid, humic substances, etc.), which react with HO%, either by competing with organic MPs for oxidation or interacting with them or by forming the respective radicals with lower oxidation potential (Michael *et al.,* 2012).

Conclusion
As a result of various industrial and domestic activities and agricultural activities, micropollutants are emerging pollutants that pose a significant threat to the environment and public health. These two pollutants cause groundwater pollution and surface water pollution, respectively. Thus, water is dangerous and poisonous for human consumption. Traditional physicochemical treatment methods are not effective at treating micropollutants in wastewater; they are expensive, require large inputs, or produce large amounts of toxic sludge. Thus, advanced oxidation technology, electric activated carbon (EAC) and biological treatment systems have recently been the focus of this field.

Conflict of interest
The authors declare that they have no conflicts of interest.

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Artificial intelligence (AI) and its applications in agriculture: A Review

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ABSTRACT

Providing food for the growing population is a challenging task, however, with historical agricultural practices, we can't meet the food requirement of the world population. We are in the need to adopt modern technology to overcome adverse climatic and cultural challenges, which are faced by current generation, that is Artificial Intelligence (AI). AI is the booming technology in the agriculture, which uses different sensors and neural networks and uses resources minimally based on need and predict the coming obstacles, which causes huge loss to crop. This review explain is, various applications of AI in the sustainable agriculture for crop managemen by overcoming realtime challenges and importance of AI in agriculture by comparing with traditional methods.

Introduction

By the 1960s, AI had already been developed in computer science. John McCarthy, who is often called the "founder" of the field, first defined artificial intelligence in 1956 as the "science and engineering of making intelligent machines" (Andresen, 2002). From the 1950s to the 1980s, most AI research focused on how to use algebra, how to prove geometric theorems, and how to learn English [Lu, 2019]. In 1983, researchers wrote about the first-time computers were used in agriculture. This marked the beginning of artificial intelligence in the field (Gouravmoy *et al*., 2018). Since then, the agricultural sector's use of computers and other forms of technology has flourished. As of 2019, AL is being used in several fields, including medicine, business, banking, education, industry, security, and agriculture (Jha *et al*., 2019). Primary jobs like farming often require a lot of hard effort, tenacity, and persistence despite little pay and an unpleasant way of life. Farmers put a lot of time and effort into growing good crops, and they have little choice but to rely on agriculture for their livelihood. However, they often make very little money and even lose money due to unfavourable environmental or

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economic situations. In a similar vein, the inability to choose an appropriate secondary occupation, which needs more time and energy, is a significant factor that contributes to the problem. Farmers will have more time and energy at their disposal, thanks to the assistance of AI, to dedicate to finding and putting into action answers to the logical problems they face. AI has been used to increase productivity, boost soil quality and crop yields, and address a wide range of other problems in the agricultural industry (Alreshidi, 2019). Driverless tractors, smart irrigation systems, fertiliser and spraying systems, smart spraying, vertical farming software, and AI-based robots are all examples of AI-based agriculture. AI-based agriculture has allowed farmers to get more done without adding staff. Self-driving tractors, also known as driverless tractors or autonomous tractors, are one example of a machine that can do tasks with a level of precision and mistake prevention that is just not feasible while a human operator is in charge [Khan *et al*., 2021]. Breeding 1.0 lasted from around 10,000 to 12,000 years ago [Meyer *et al*., 2012], during which time people from all across the globe discovered and cultivated almost 7,000 different types of food plants. The discovery of inbreeding depression in the late 19th and early 20th centuries marked the beginning of breeding stage 2.0. Replicated field trials, controlled crossings, statistical analyses, formal experimental designs, hybrid breeding, pedigree-based estimates of breeding values, and precise yield measurement at scale (e.g., with multirow combines) were just some of the advances made in the science of breeding during this time [Moran and Smith 1918]. About 30 years ago, molecular markers and genomic data started to augment phenotypic data, marking the beginning of breeding 3.0 [Meuwissen *et al*., 2001]. Large amounts of omics data and the fast development of informatics technologies are ushering in Breeding 4.0 [Wallace *et al*., 2018]. Since crop domestication marked the beginning of the plant breeding process, new methodologies mediated by diverse technological revolutions have continually expanded the science to quicken the speed, raise the accuracy, and increase the precision of plant breeding [Zargar *et al*., 2015]. This research has already delivered the green revolution by generating semidwarf cultivars, nutrient-responsive cultivars, and hybrid cultivars over the course of the last decade [Bhat et al., 2021]. To generate agricultural cultivars at a faster speed with better accuracy and greater precision, however, more accurate, high-throughput techniques are needed in light of population expansion, shrinking arable land, and climatic changes. It has been proposed that the relatively new area of artificial intelligence offers amazing potential to help in the creation of climate-resilient smart crops. Artificial intelligence (AI) is the fastest-growing field in computer science at the moment because it allows programmers to make machines that are as smart as humans [Harfouche, 2019]. Modern computing is often characterised by phrases like "big data," "machine learning," and "artificial intelligence" [Cravero and Seplveda, 2021]. Massive data sets with unusually complicated structures that challenge traditional data analysis methods are at the heart of the big data movement [Supriya and Deepa, 2020]. As used here, AI programmes a machine to make decisions in complex scenarios where human effort would be inefficient due to the time and effort required [Berente *et al*., 2021]. Machine learning (ML) is a subfield of artificial intelligence in which computers learn to make inferences from large collections of examples. The collection of meteorological or Earth System-related measurements, as well as high spatial and temporal resolution Earth System Model (ESM) outputs for analysis, is what constitutes "big data" in the context of weather and environmental applications; machine learning (ML) is the refinement or discovery of new linkages between locations, times, and quantities in the datasets (such as where sea surface temperature features aid the weather prediction for months over land regions), etc [Huntingford *et al*., 2019]. This novel usage of computer memory brings computations much closer to the site where data is stored, improving both efficiency and accuracy [Huntingford *et al*., 2019]. The primary focus of using AI in breeding is to provide continuous farm monitoring, which complements the job of the breeder. Indeed, with farm automation and data standardisation, breeders may be able to devote more time to higher-value tasks by spending less time in their facilities. A significant advantage of AI is the time it saves in identifying and processing data. Gaining self-assurance and the ability to respond quickly allows breeders and technical advisers to take decisive action when it is needed [Talaviya *et al.*, 2020].

Application of AI in agriculture

Soil management

In addition to water, nitrogen, phosphorus, potassium, and proteins, which are all essential for healthy crop growth and development, the soil is one of the most significant aspects in agriculture's success [Eli-Chukwu and Ogwugwam, 2019]. Compost and manure boost soil porosity and aggregation, while a reduced tillage approach prevents soil from physically degrading. Negative influences, such as soil-borne diseases and pollutants, may be reduced with proper soil management (fig-1) [Eli-Chukwu and Ogwugwam, 2019]. Soil maps, which employ AI to highlight the interactions between soil and landscape, as well as the different layers and proportions of soil below ground, are one more example [Elijah, 2018].

Fig-1: AI in soil management

Weed management

Weeds are one of the main things that bring down a farmer's expected profit. Dried bean and corn yields may drop by half if weed invasion is not controlled, while wheat yields might drop by almost half due to weed competition. Some weeds are harmful and even pose a hazard to public health, but they nevertheless compete with crops for water, nutrients, and sunshine [Eli-Chukwu and Ogwugwam, 2019]. Although weed spray is widely used, there is concern that it may be harmful to human health and that its misuse may cause environmental damage. Therefore, lab-tested AI weed identification(fig-2) systems have been developed to determine the appropriate spray dosage and correctly spray the intended area, reducing expenses and the possibility of crop damage [Partel, 2019].

Crop production

Crop efficiency and production may be increased with the use of artificial intelligence-based technologies, as stated by Talaviya *et al.* (2020). These technologies aid in addressing difficulties related to weeding, irrigation, crop establishment, and crop monitoring. Concerns such as unpredictable climate change, a rapidly expanding population, and food poverty have pushed the adoption of artificial intelligence to assure sustainable agriculture. Ghosh and Singh (2020) claim that AI has been used throughout several subfields of agriculture, including but not limited to general crop management systems, pest and disease control, soil and irrigation management, weed management, and yield prediction. (fig-3). Drones and other robots are increasingly being used by farmers in a variety of applications around the farm.

Irrigation

It is critical that we construct an irrigation system that guarantees the correct use of water resources since 85 percent of freshwater is used on agricultural operations worldwide (Talaviya *et al.*, 2020). Soil has to be kept wet for plant development, and this is what irrigation is all about. Low crop yields are a direct consequence of inefficient irrigation systems, which may also contribute to the waste of water resources and the leaching of chemicals in the soil [Eisenhauer, 2021]. Soil and water management are obviously crucial to preventing crop failure and soil degradation. In agriculture, irrigation is often performed by farmers using antiquated irrigation technologies like watering cans or buckets. These antiquated systems should be replaced with current approaches using artificial intelligence. Artificial intelligence (AI) used in a machine-based irrigation control system guarantees effective management of both soil and water [Angelin Blessy and Kumar, 2021]. A well-designed irrigation system will boost agricultural production by boosting yields and maintaining output, whereas a poorly designed system will have the opposite effect and diminish crop productivity. In order to save water during

Fig-2: AI in weed management

Fig-3: AI in crop production

irrigation and lessen the need for farmhands, agricultural monitoring is used [Shekhar *et al.*, 2019]. Mechanical irrigation systems are now widely used in agriculture(fig-4).

Weather & price forecasting

One of the difficulties is that, as we have previously said, climate change makes it more difficult for farmers to estimate the optimal times to harvest, sow seeds, and prepare the land. Other difficulties include the fact that climate change also makes it more expensive. Farmers will be able to acquire information on weather analysis and make educated choices about the crop to produce, the seeds to sow, and the time of harvesting with the assistance of AI weather forecasting (fig-5). This will allow farmers to get information on the weather. Price forecasting allows farmers to maximize their earnings by predicting how much their products will be worth in the weeks to come. This allows farmers to budget their expenses more effectively.

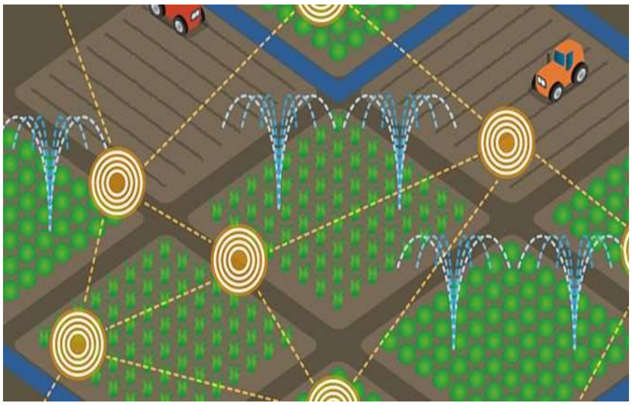

Fig-4: AI in irrigation

Pest and disease management

Farmers worry a lot about pest infestation and crop disease since they have both been related to

Fig-5: AI in weather forecasting

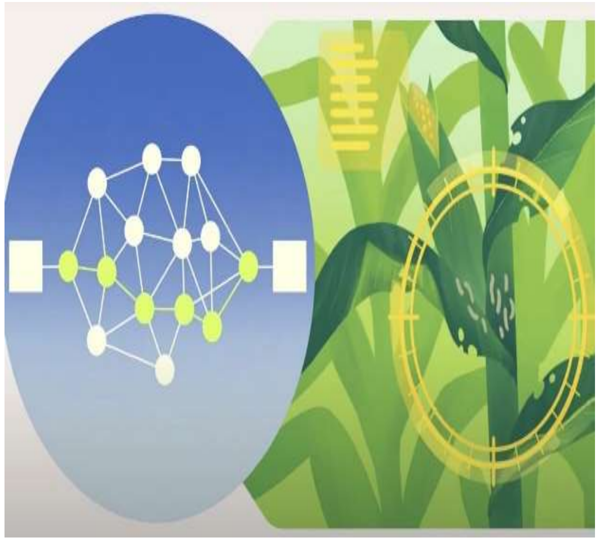

Fig-6: AI in pest and disease identification

generating a big economic loss in agriculture [Gouravmoy*et al.*, 2018]. This is one of the major challenges facing agriculture today. Pests and crop diseases not only result in monetary loss but also endanger the ecosystem and lead to food insecurity [Liu *et al.*, 2020]. Because of this, the use of artificial intelligence to identify agricultural illnesses and provide treatment recommendations [Clara, 2019). The use of AI for early identification of pests and illnesses is crucial for efficient management in agricultural settings. "AI and machine learning may help identify those places most at risk of invasions or outbreaks and help with strategies to control the spread of invasives or illnesses," Bestelmeyer *et al.* [2020] write. Conventional farmers have relied on their expertise to combat plant diseases and pests. Businesses now employ IT systems for everything from pest control to disease analysis and control recommendations [Sharma 2021]. Through this method of early identification and management, agricultural plants will suffer less damage from pests and diseases, resulting in a greater harvest(fig-6).

Phenomics

The study of plant phenotypes, or outward physical characteristics, is known as "plant phenomics" (Kumar *et al.*, 2015). With the potential for high-throughput analysis in agricultural fields, plant field phenotyping has gained a lot of interest in recent years (Selvaraj *et al.*, 2020). Improvements in quantitative agricultural characteristics evaluation may be attributed to the use of machine learning techniques and other technical advancements in the realm of picture analysis (fig-7). (Zhao and Rewald, 2016; Selvaraj *et al.*, 2020; Dobbels and Lorenz, 2019). CNN-based identification and analysis of wheat spikes utilising wheat field trials photos taken over one planting season produced an average accuracy of 88 to 94 percent across varied sets of test photographs. CNN (Convolutional Neural Networks) has shown superior performance, making it a reliable model for genome-based selection and prediction in plant breeding (Hasan *et al.*, 2018). Plant image segmentation, which required the collection and analysis of several photos of plants, also made use of the RF method (Carvalho *et al.*, 2022). Model projections led to the identification of a wide range of plant growth characteristics (Selvaraj *et al.*, 2020).

Precision farming

"Right location, right time, and right goods" sums up precision farming. The labor-intensive aspects of farming may be replaced with the considerably more precise and manageable precision farming technology. The measurement of plant stress is one example of precision farming. This may be gleaned from various plant sensor data and high-resolution

Fig-7: AI in phenomics

photos. Sensor data is used to train a machine learning model for stress detection (fig-8).

Fig-8: AI in precision farming

Plant breeding

When used in agriculture, artificial intelligence (AI) is an intriguing high-tech system that offers unlimited possibility; this, in turn, opens up new vistas for digital breeding [Montesinos-López *et al*. 2018]. High-throughput genomics and phenomics for advanced breeding are only two examples of how artificial intelligence (AI) is being used to speed up the process of developing new plant varieties [Harfouche *et al*., 2019; Esposito *et al*., 2020; Reinoso-Peláez *et al*., 2022 and Crossa *et al*., 2017]. More and more, ML methods are being used for genomic prediction, genomic selection, and marker-assisted selection (Reinoso-Peláez *et al*., 2022; Crossa *et al*., 2017). Hundreds of millions of dollars have already been spent by agricultural giants like Monsanto and John Deere in developing such technology that can use vast data on soil type, seed variety, and weather to help farmers decrease costs and increase yields (Faulkner *et al*., 2014). Both of their operations rely on data from similar sources, such as weather predictions and Google Maps. Moreover, they may obtain information from agricultural machines that have been wirelessly sent to the cloud (Stergiou *et al*., 2017). Companies such as Nippon Electric Company, Limited (NEC; headquartered in Minato, Tokyo, Japan) and Dacom (headquartered in Santa Clara, USA) used environmental sensors and massive data analytics technologies as part of a precision-farming experiment in Romania. Increased agricultural output is a direct result of modern agriculture's increased use of data and computing systems (Bilali and Allahyari 2018). The complexity of agricultural data sets presents challenges for creative architecture and frameworks, algorithms, and analytics, all of which are essential for gleaning the value and hidden information contained therein (Priya and Ramesh, 2020). Current efforts in artificial intelligence study methods including machine learning (ML), deep learning (DL), and predictive analysis (PA) have the goal of bettering our capacities for forethought, reflection, deliberation, and action (Shaw *et al.*, 2019). Breeders of plants are working on systems to help researchers learn more about how plants respond to different climates [Jeong *et al.*, 2016]

(fig-9).

Fig-9: AI in Plant Breeding

Plant genomics

In order to gather massive datasets and develop novel biological hypotheses, genomics typically employs ML, the discipline of using programming to train computers to learn from data. To get fresh insights from the flood of genomics data, more expressive ML models are necessary. Deep learning's innovative use of large datasets has reshaped fields like natural language processing and computer vision. In addition, deep learning is a cutting-edge method for processing data and images that shows great promise and vast potential. Additionally, deep learning has just entered the agriculture industry after being effectively implemented in a number of other sectors (Bioshop, 2016). There has been a lot of research on the efficacy of various deep learning methods for genomic prediction in recent years. But unlike conventional statistical learning techniques, deep learning approaches are nonparametric models, meaning they can easily accommodate a wide variety of input-output relationships (Kukar *et al.*, 2007). For genomic selection, there is strong evidence that deep learning algorithms capture nonlinear patterns more successfully than conventional genome-based techniques (GS). These methods provide a meta-image of GS efficiency and show how these methods might be useful in solving challenging plant breeding challenges. Moreover, deep learning algorithms may integrate data from numerous sources, and they have shown the capacity to enhance prediction accuracy for huge plant breeding datasets, as is frequent in gene selection-assisted breeding. Therefore, it is essential to use deep learning methods on huge datasets for both training and evaluation (Bernardo, 2008).

Produce harvesting

Mechanizing crop and harvest management is essential for farmers in order to cut down on labour costs and increase agricultural output [Waleed *et al.*, 2020]. Mechanization in crop management and product harvesting is highly sought after by farmers due to the time and labour savings it provides. The use of drones for crop monitoring, robots in farming, machine learning and big data in farming, etc., have all benefited greatly from AI's contribution to mechanisation in agriculture [Mentsiev *et al.*, 2021]. Artificial intelligence has been shown to improve agricultural plant monitoring, which in turn speeds up harvesting, processing, and distribution of crops (Fig-10) [Talaviya *et al*, 2020]. Since the burden is decreased thanks to the application of AI, the issue of needing numerous people is resolved. Even nut harvesting can be done by robots and AI now [Mentsiev *et al*, 2021]. Unlike human workers, robots may be taught to work at a quicker pace while harvesting [Alreshid 2019]. Mechanized harvesting methods, such as harvesting robots equipped with sensors to detect their surroundings, have also been developed [Montoya-Cavero *et al*, 2021]. (Table-1).

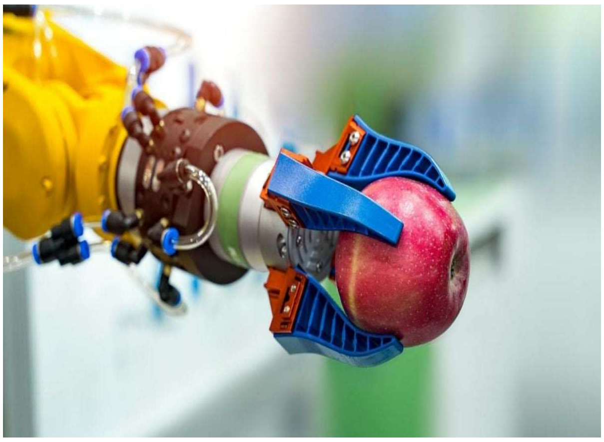

Fig-10: AI in harvesting

Table 1. Different AI techniques in agriculture management

Management	Technique	Strength	Limitation	References
Soil	MOM	Minimizes nitrate leaching, maximizes production.	Takes time. Limited only to nitrogen.	Li, 2000
	Fuzzy Logic: SRC-DSS	Can classify soil according to associated risks.	Needs big data. Only a few cases were studied.	Lopez *et al*., 2008
	DSS	Reduces erosion and sedimentary yield.	Requires big data for training.	Montas, and Madramootoo, 1992
	ANN	Can predict soil enzyme activity. Accurately predicts and classifies soil structure.	Only measures a few soil enzymes. It considers more classification than improving the performance of the soil.	Tajik *et al*., 2012
	ANN	Can predict monthly mean soil temperature	Considers only temperature as a factor for soil performance.	Levine *et al*., 1996
	ANN	It predicts soil texture	Requires big data for training. Has restriction in areas of implementation.	Bilgili, 2011
	ANN	Able to predict soil moisture.	The prediction will fail with time as weather conditions are hardly predictable.	Zhao *et al*., 2009
	ANN	Successfully reports soil texture.	It does not improve soil texture or proffers solution to bad soil texture.	Elshorbagy, and Parasuraman, 2008
	ANN	Cost-effective, saves time, has 92% accuracy	Requires big data.	Chang, and Islam, 2000
	ANN	Can estimate soil nutrients after erosion.	Its estimate is restricted to only NH_4.	Behrens *et al*., 2005
Crop	CALEX	Can formulate scheduling guidelines for crop management activities	Takes time	Plant, 1998
	PROLOG	Removes less used farm tools from the farm.	Location-specific.	Lal *et al*., 1992
	ANN	Predicts crop yeild.	Only captures weather as a factor for crop yeild.	Snehal, and Sandeep, 2014
	ROBOTICS-Demeter	Can harvest up to 40 hectares of crop	Expensive: Uses a lot of fuel.	Pilarski *et al*., 2002
	ROBOTICS	Has 80% success rate in harvesting crops	Slow picking speed and accuracy.	Henten *et al*., 2002
	ANN	Above 90% success rate in detecting crop nutrition disorder.	A little number of symptoms were considered.	Song and He, 2005

	FUZZY Cognitive Map	Predict cotton yield and improve crop for decision management.	It is relatively slow.	Papageorgiou *et al.*,2011
	ANN	Can predict the response of crops to soil moisture and salinity.	Considers only soil temperature and texture as factors.	Dai *et al.*, 2011
	ANN and Fuzzy Logic	Reduces insects that attack crops.	Shows inability to differentiate between crop and weed	Yang *et al.*, 2003
	ANN	Can accurately predict rice yield.	Time-consuming, limited to a particular climate.	Ji *et al.*, 2007
Disease	Computer vision system (CVS), genetic algorithm (GA), ANN	Works at a high speed. Can multi- task.	Dimension-based detection which may affect good species.	Balleda *et al.*, 2014
	Rule-Based Expert, Data Base (DB)	Accurate results in the tested environment.	Inefficacy of DB when implementing in large scale.	Balleda *et al.*, 2014
	Fuzzy Logic (FL), Web GIS	Cost-effective, eco-friendly.	Inefficiency due to scattered distribution. Takes time to locate and disperse data. The location of the data is determined by a mobile browser.	Jesus *et al.*, 2008
	FL Web-Based, Web-Based Intelligent Disease Diagnosis System (WIDDS)	Good accuracy. Responds swiftly to the nature of crop diseases.	Limited usage as it requires internet service. Its potency cannot be ascertained as only 4 seed crops were considered.	Kolhe *et al.*, 2011
	FL & TTS converter	Resolves plant pathological problems quickly.	Requires high speed internet. Uses a voice service as its multimedia interface.	Kolhe *et al.*, 2011
	Expert system using rule-base in disease detection	Faster treatment as diseases are diagnosed faster. Cost effective based on its preventive approach.	Time consuming. Needs constant monitoring to check if pest has built immunity to the preventive measure.	Munirah *et al.*, 2013
	ANN, GIS	95% accuracy	Internet-based. Some rural farmers will not have access.	Liu *et al.*, 2006
	FuzzyXpest provides pest information for farmers. It is also supported by internet services.	High precision in forecast.	Internet dependent.	Siraj and Arbaiy, 2006
	Web-Based Expert System	High performance.	Internet and web based.	Virparia,2007
	ANN	Has above than 90% prediction rate.	The ANN does not kill infections or reduces its effect.	Wang *et al.*, 2006
Weed	ANN, GA	High performance. Reduces trial and error.	Requires big data.	Tobal and Mokhtar, 2014
	Optimization using invasive weed optimization (IVO), ANN	Cost effective, enhanced performance.	Adaptation challenge with new data.	Moallem and Razmjooy, 2012

	Mechanical Control of Weeds. ROBOTICS. Sensor machine learning	Saves time and removes resistant weeds.	Expensive. Constant use of heavy machine will reduce soil productivity.	Brazeau, 2018
	UAV, GA	Can quickly and efficiently monitor weeds.	Has little or no control on weeds. Expensive.	Ortiz *et al.*, 2016
	Saloma expert system for evaluation, prediction & weed management.	High adaptation rate and prediction level.	Requires big data and usage expertise.	Stigliani and Resina, 1993
	Support Vector Machine (SVM), ANN	Quickly detects stress in crop that will prompt timely site–specific remedies.	Only detects low levels of nitrogen.	Karimi, 2006
	Digital Image Analysis (DIA), GPS	Has above 60% accuracy and success rate.	Its success was achieved after 4 years and as such, it is really time consuming.	Gerhards and Christensen, 2003
	UAV	High rate of weed detection within a short period of time.	It is really expensive and requires vast human expertise.	Lopez Granados, 2011
	Learning Vector Quantization (LVQ), ANN	High weed recognition rate with short processing time.	The method of data input used affected the AI's perfromance.	Yang *et al.*, 2002

Challenges of AI adoption in agriculture

1. As more farmers become aware of the ways in which artificial intelligence might make farming more sustainable, adopting this technology may seem to be the next obvious step. On the other hand, there are still certain significant difficulties that are common knowledge, and they are as follows: Lack of familiarity with ai machines
2. Lack of experience with emerging technologies
3. Privacy and security issues

Conclusion

In light of the massive growth in population and therefore high demand for food, the conventional method of farming is no longer viable. Since this poses a global crisis, immediate and extreme measures are required. To satisfy the world's need, we must immediately adopt more efficient methods of agricultural production. Artificial intelligence has shown to be a groundbreaking technology with vast applications throughout the whole agricultural value chain. Plowing, seeding, fertilising, watering, protecting, and harvesting are all made easier using AI. This has helped ensure that the agricultural system is machine-driven, which has increased output while maintaining or improving quality. The research shows that using AI to automate agricultural processes will lead to significant labour savings, lower overall production costs, and higher outputs thanks to greater input efficiency. So, there will be a lot of productivity and a good harvest. The trajectory of AI is difficult to foresee. The purpose of artificial intelligence in the 1990s was to improve R&D efforts, but will that continue to be the case in the future? Examining the differences between robots and humans is a significant focus of current study. A shift in human responsibilities is inevitable if machines begin replacing human labour. In the future, thanks to the efforts of researchers, it's possible that machines will perform most of our job and robots will accompany us wherever we go. Soon, robots will be used in agriculture, leading to increased yields of higher quality.

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Conflict of interest

The authors declare that they have no conflict of interest.

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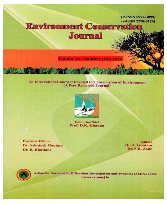

Role of agroforestry systems in enrichment of soil organic carbon and nutrients: A review

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ABSTRACT

Monocropping systems have intensively exploited natural resources in recent decades, and the indiscriminate use of inorganic fertilizers, combined with agro-chemicals, has resulted in the deterioration of natural resources such as soil and water, resulting in the loss of soil fertility. Agroforestry is an ideal scientific strategy for eco-restoration of degraded areas and sustainable resource management when compared to mono cropping systems. It is a land management and farming strategy that aims to not only produce food from marginal agricultural land, but also to significantly improve the quality of the environment and soil. When compared to regular crop removal in a solo cropping system, leaf litters and their breakdown under tree-based vegetation favour nutrients enrichment. The adoption of an agroforestry system resulted in the accumulation of soil organic carbon, increased the availability of macronutrients and micronutrients, and improved the microenvironment for plant growth. As a result, pairing suitable tree species with agricultural crops can contribute in the maintenance or enhancement of soil fertility. Based on these findings, it is advised that farmers adopt agroforestry systems since they have enormous potential to improve soil fertility, leading to increased crop output and food security.

Introduction

Agroforestry is a specialized form of land use that combines trees with livestock or agricultural crops to provide enhanced ecological and environmental advantages. It's an ideal scientific practice for restoring degraded lands and managing resources in an efficient manner (Sileshi *et al.,* 2020). In both rural and urban environments, trees in general can offer a wide range of environmental advantages, and they are crucial to the ecosystem services provided by natural areas (, Barrios *et al.,* 2018; Mexia *et al.,* 2018; Blanco *et al.,* 2020). Despite the fact that the advantages that trees can offer on rural properties, such as food security, household income, economic stability, and thermal comfort (shade), are frequently connected to their goods, such as fruit, timber, or other items, trees may additionally enhance the cycling of nutrients and have beneficial impacts on soil physical and chemical characteristics when they are included in agricultural systems (Isaac *et al.,* 2007; Torralba *et al.,* 2016; Rodriguez*et al.,* 2021). Concerns regarding agriculture's long-term viability are rising. The environment has been harmed by overuse and underuse of fertilizers, as well as poor

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resource management. Harsh weather conditions, population pressure, land limits, and the adoption of conventional soil management practices have all lowered soil fertility in developing countries (Henao and Baanate, 1999). The process of reducing soil erosion results in an increase in soil fertility (Garcia *et al.,* 2017) and reduce runoff (Mu *et al.,* 2018) and maintain soil organic matter (Bonanomi*et al.,* 2020)This results inimprovement of the soil's physical, chemical, and biological qualities, increased nitrogen (N) input from N-fixing plants, excavation of minerals from deeper horizons by roots, and recycling of those minerals through litter fall on the ground. Based on the current population status expansion and higher demand on agricultural areas, there is a desire for more intensive land usage (Wang *et al.,* 2018). Crop residue burning is the least expensive way to prepare ground for planting, but it might interfere with Ncycling and deposition processes, resulting in a loss of soil fertility (Jusoch *et al.,* 2013; Bhutiani and Ahamad, 2019) and, as a result, reducing the recovery of natural vegetation during fallow periods. Phosphorus (P) and N being the most limiting elements for crop productivity in the cropping land (Reza *et al.,* 2019), and the high price of inorganic fertilizers prevents most small-holder farmers from using them in sufficient quantities (Akpan *et al.,* 2012). Many crops have been observed to be deficient in macronutrients, and the severity of these deficiencies varies based on agroecological systems, soil types, farming practices and human activities (Shukla and Behera, 2014).Organic matter, physical properties, and nutrient levels must all be sustained in order for soil fertility to be maintained. Changes in soil properties, such as pH, soil organic carbon (SOC), soil structure, macronutrients (Aluko and Fagbenro, 2000) and micronutrients (Dhaliwal and Walia, 2008) influenced soil fertility and production. Agroforestry systems based on *Populus, Eucalyptus* and *Melia* have developed as an alternative option for crop diversification in north-west India, boosting soil fertility, productivity, and net profitability while also helping to mitigate the negative effects of climate change (Chaudhari *et al.,* 2014; add one more citation here). Trees contribute to soil fertility preservation by fixing Nand returning organic content through leaf fall (Rosenstock *et al.,* 2014), resulting in a high proportion of organic-P in the soil. According to Wood *et al.* (2007) soil fertility is linked to the amount of litter fall, the quality of the litter, the rate of nutrient mineralization and breakdown. In comparison to solo cropping or traditional farming systems, research have shown that including diverse tree species such as *Acacia, Eucalyptus* and *Poplar and Mahogany* improves pH, electrical conductivity (EC), organic matter, available macro and micronutrients in soil (Rosenstock *et al.,* 2014; Dinesha and Dey, 2023). As a result, better methods of farming not only improve soil fertility and productivity, but they also have the potential to make soil a net sink for carbon, lowering CO_2 levels in the atmosphere (Naik *et al.,* 2017).

Crop productivity is mostly influenced by soil fertility. Since soil fertility and farm productivity tend to be strongly correlated, addressing the issue will have a direct impact on agricultural yields. It has been proven that using chemical fertilizers along with organic source on newly created high-yielding crop types can increase crop yields by a ratio of three to five or more (Mamnabi *et al.*, (2020)). It has, however, fallen into a number of issues. Fertilizers are expensive to create in terms of energy resources, and their continued widespread use has a negative impact on the environment. Because of physical soil deterioration or a lack of micronutrients, for instance, yield responses to fertilizers have decreased. Above all, a significant portion of underprivileged farmers are unable to pay for expensive fertilizers and other purchased inputs, nor do they have the resources to assume the associated risk. Farmers have also had to spend a lot of money buying chemical fertilizers due to their high cost and limited availability. An economic analysis confirms that this method of farming is neither sustainable nor profitable. Thus, there is a need for proper farming techniques that would reduce inputs while boosting yields by conserving the natural fertility of the soil. Rapidly growing and N-fixing plant species can be used in agroforestry as a quick approach to add organic matter to the soil.

Effect of agroforestry systems on soil organic carbon and nutrient availability

The fertility of the soil is almost solely responsible for crop productivity. This in turn has an impact on household food security. Soil fertility levels must rise in order to maintain good crop productivity and

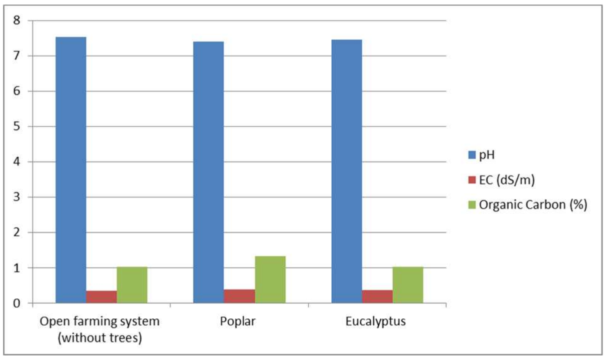

Figure 1: Effect of various agroforestry and open agricultural systems on soil pH, EC and SOC at a depth of 0–30 cm (Sharma *et al.,* 2022)

food security. However, soil infertility has been caused by subpar agricultural methods as well as other occurrences like soil erosion. By controlling the site's microclimate, trees and growing crops help to improve the environment. Organic matter can accumulate in the soil and nutrient cycling is made possible by litter fall, root elongation, and crown expansion, resulting in improved root zone characteristics and soil fertility (Laganiere *et al.,* 2010; Dinesha and Dey, 2023). According to Jobbage and Jackson (2001) micronutrient profiles are mainly characterized by rooting depth and distribution. Large amounts of nutrients can be absorbed below the rooting zone of crops by trees with deep and extensive root systems, which can then redistribute those nutrients to the topsoil (Allen *et al*., 2004). Through litter fall and root turnover, which varies with the type of tree, intercrops, plantation age, decomposing rate, season, and spacing, significant amounts of nutrients are returned to the soil. (Singh 2009, Laik *et al.,* 2009, Singh and Singh, 2016).

Effect of agroforestry on soil organic carbon

The mineral soil can be penetrated by the deep root systems of trees. Significant sources of SOC in deeper soil layers come from root-derived C inputs (Kell, 2012). In deeper soil layers close to trees, agroforestry systems accumulate more carbon than they do in shallower soil layers away from trees (Nair *et al*., 2010). Peichl *et al*. (2006) studied carbon sequestration in a poplar intercropping system that is 13 years old and found that it was four times higher than in a solo cropping system. He compared the carbon concentrations in soil from solo cropping sites, poplar intercropping sites, and spruce intercropping sites. Carbon concentrations were higher in poplar intercropping than in other intercroppings, according to the findings. According to Chauhan *et al*. (2012), soil enrichment through litter and roots increased organic carbon in the surface layer of soil under poplar-based agroforestry compared to a no-tree control. Stefano and Jacobson (2018) conducted a meta-analysis of the literature recently published. They discovered that switching from non-tree systems to agroforestry systems boosted SOC storage in general. In a 28-year-old long term experiment under Eastern Himalayas, Yadav *et al*. (2021) studied the effect of agroforestry system on different carbon fractions in 0-15 cm of soil depth and they revealed that very labile, labile, less labile and non labile fractions were significantly higher under sisoo+pineapple system (6.44, 4.45, 5.38 and 5.86 mg/h) as compared to sole cropping of pinapple (3.19, 4.41, 2.75 and 2.42 mg/h).

In subtropical plantations in China, Wang *et al.* (2013) studied the effect of different tree species mixture on organic carbon stocks of soil and found that SOC stocks were 14.3 and 8.1% higher in mixed plantations than that of *Pinus massoniana* and *Castanopsis hystrix* plantations in 0-20 cm soil depth. These differences in SOC stocks among plantations were attributed to root biomass, leaf litter fall input and soil Nstock. The results show that silvicultural approach of mixture of *C. hystrix* versus *P. massoniana*can be a better option for soil organic carbon (SOC) sequestration as compared to monoculture plantations in subtropical China. Guo *et al*. (2018) investigated seasonal and vertical variations of SOC in five different planting systems, a pure wheat (*Trticum aestivum*) field, a pure ginkgo (*Gingko biloba*) system, a pure metasequoia (*Metasequoia glyptostroboides*) seedling system, a ginkgo and metasequoia-based agroforestry system.. The results showed that the ginkgo and wheat agroforestry system had significantly higherSOC throughout the year when compared to other systems at varying soil depths i.e., 0-10 and 10-20 cm. SOC concentration was lower in the pure *Metasequoia* and pure *Ginkgo* planting systems than in the other planting systems. The cause for this decline was a reduction in tree input and a reduction in fine root biomass. This demonstrates that agroforestry systems are more efficient and resulted in a higher soil C sink buildup. Matos *et al*. (2011) investigated the impacts of changing land use from silvopasture to arable land, grassland, continuous arable land, and silvopasture on the dynamics of (SOC). Carbon stocks decreased by 47% on average from upper soil depth (0-10) cm to lower soil depth (10-20 cm). In comparison to silvopasture-arable land and arable land systems, soils under silvopasture had the highest total organic carbon in the upper layers.

Effect of agroforestry on soil macronutrients

The most important benefit of the agroforestry system is the improvement in soil fertility maintenance (Singh, 2010). In addition to reducing soil carbon loss due to erosion, agroforestry systems aid in nutrient replenishment, which is lost when biomass is harvested (Vallejo *et al.,* 2012). In India, a poplar-based agroforestry system and rice-wheat, maize-wheat, and cotton-wheat rotation farmlands were compared to examine P availability and speciation by Prakash *et al.* (mention year) and they concluded that in comparison to other conventional land uses agroforestry produced more organic P and less inorganic P as well as having a higher SOC content. Due to lesser P availability, intercropping appeared to reduce P nutrition. In temperate climatic conditions in Belgium, Pardon *et al*. (2017) evaluated the impact of tree rows bordering arable fields and alley cropping on nutrient availability in a plough layer (0-23 cm) at different distances from the tree rows and with different tree ages and sizes. The average increase in soil nutrient stocks in the agroforestry system was 86, 108, 45 and 16 kg/h of P, K, Mg, and Na, respectively. Arora *et al.,* (2021) assessed the effects of different land use systems on soil chemical characteristics in the 0–15 m of soil depth in the Shiwalik foothills of northwest India. They reported that under cultivated land available P and available K (27.9 and 189.9 kg/h) were comparatively higher than in agri-horticulture (21.0 and 151.2 kg/h) and agroforestry (22.2 and 156.0 kg/h) systems, respectively. The continual addition of inorganic fertilizers might have been the reason for the higher availability of P and K in farmed systems.

Sarvade *et al.* (2014) studied the effect of intercropping of four tree species viz., *Populus deltoides* (T1), *Eucalyptus camaeldulensis* (T2), *Leucaena leucocephala* (T3) and *Melia azedarach* (T4) planted at 3.0×1.0 m^2 (S1), 3.0×1.5 m^2 (S2), 3.0×2.0 m^2 (S3), 3.0×2.5 m^2 (S4) spacing with wheat (*Triticum aestivum L*) variety PBW-502 on Available soil N, P and K. The results showed that available N and P were significantly influenced by tree species and their spacing treatments whereas K_2O was non-significant. The highest available soil N (83.8 mg/kg), P (7.04 mg/kg) and K (73.4 mg/kg) were recorded under *Leucaena leucocephala*. The S3 tree spacing recorded highest available soil N (81.8 mg/kg), P_2O_5 (7.05 mg/kg) and K_2O (72.1 mg/kg). The findings showed that highest values for soil nutrients were recorded from T3×S3 treatment combination. Mineralization of organic forms and atmospheric Nfixation are the key ways in which these nutrients are made available to plants in agroforestry systems. In *Melia dubia*-wheat agroforestry system, Narender *et al.* (2021) studied the effect of agroforestry system on SOC , Nand potassium (K) in surface and sub-surface soil layers under semi-arid region of Haryana. They observed that available N, available P and available K were significantly higher under tree based system (128.65, 11.88 and 293.15 kg/h) as compared to sole cropping wheat without tree (108.89, 10.58 and 246.41 kg/h), respectively. Similar results were observed forSOC. Also, it was revealed that SOC, available N, available P and available K were significantly higher in surface soil layer (0-15 cm) as compared to sub-surface soil layer (15-30 cm). So, in order to make the soil enrich in nutrients agroforestry system can be considered as suitable option as compared to sole cropping system. An experiment was conducted by Sharma *et al.* (2022) to demonstrate the effect of agroforestry system on soil available N, P and K in 0-30 cm of soil depth (Figure 2) and concluded that available N and K_2O was significantly higher under popular and eucalyptus based agroforestry system as compared to open farming system. While P_2O_5 was not significantly affected by the different land uses, although highest P_2O_5 was observed under eucalyptus-based agroforestry system (20.2 kg/h) followed by popular (19.6 kg/h) and least under open farming system (17.7 kg/h). Pardon *et al.* (2017) studied the effect of alley cropping and arable fields bordered by tree row on nutrient availability with in a plough layer (0-23 cm) in temperate climatic conditions of Belgium having different distances from the tree rows and with

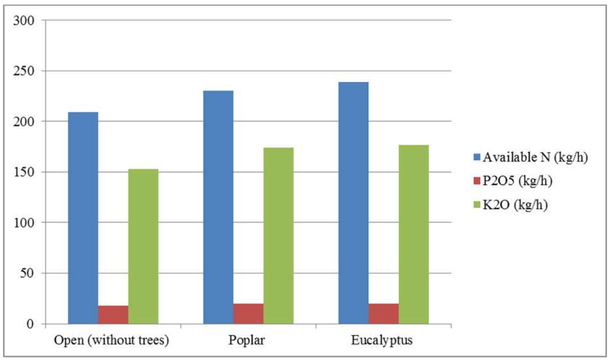

Figure 2: Effect of various agroforestry and open agricultural systems on soil available N, P and K at a depth of 0–30 cm (Sharma *et al.,* 2022)

different tree ages and sizes. The results revealed that average increase in soil nutrient stocks in agroforestry system was 86, 108, 45 and 16 kg/h of P, K, Mg and Na respectively when compared to control. The average total N stock increased by 56 kg/h in 0-23 cm soil layer of transects closer to the tree row. This increased soil Nconcentrations appeared to be strongly linked with buildup of SOCconcentrations. Yang *et al.* (2018) found that total Pcontent was higher under trees than abandoned land which can be due to organic acids (secreted by roots) activating P and improving P availability.

Effect of agroforestry on soil micronutrients

Micronutrients are essential for plants to complete their life cycle; they are utilised in small amounts to promote healthy plant growth, improve soil quality, boost crop yield, and supply balanced nutrition to crops (Lal, 2009). The long-term cultivation of a specific type of soil system changes the physical and chemical qualities of the soil, as well as the micronutrient content in the soil, making it available for plant growth. Different land uses alter micronutrient availability and redistribution through changes in soil chemistry and OM (Doran, 2002). Ram *et al.* (2022) concluded that among different land use systems higher zinc, iron, copper, and manganese soil were found under agroforestry-based systems (poplar+turmeric and eucalyptus+turmeric) as compared to fallow uncultivated land and sole cropping system in 0-20 cm of soil depth (Figure 3). In deep loamy alluvial soils, Kaur *et al.* (2020) conducted an experiment to study the impact of agroforestry system of different ages on micronutrient availability. They observed that availability of Zn, Cu, Fe and Mn was significantly higher under 30 year-old popular based agroforestry system as compared to 10 and 20 years old system. The availability of micronutrients in surface soils of agroforestry land use systems was also found to be higher when compared to fodder-fodder and fallow land because of higher organic matter content, which results in proper aeration and protection of micronutrients in bound forms from oxidation and precipitation, and supplied soluble chelating agents, increasing the solubility of micronutrient contents (Saha *et al.,* 2019).

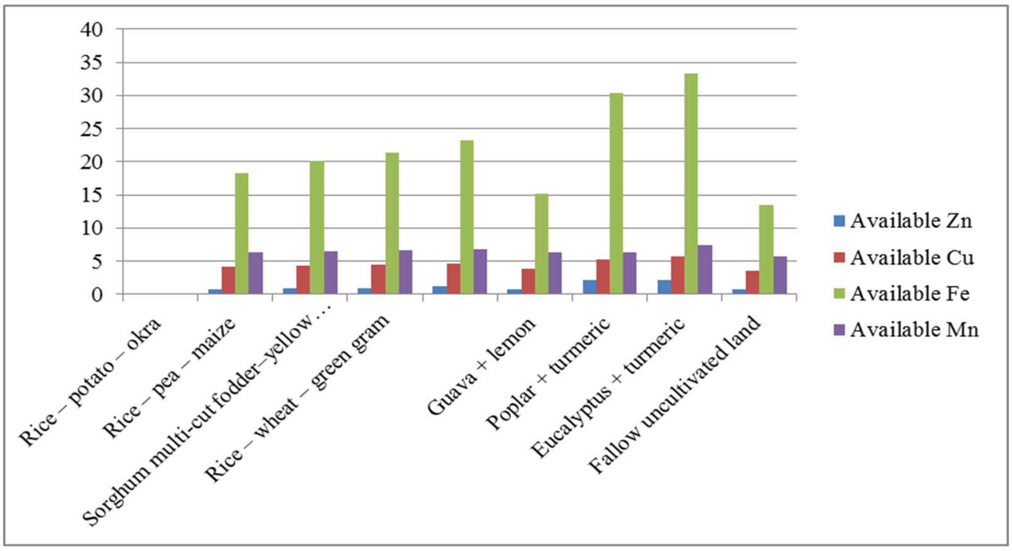

Figure 3: Micronutrient concentration (mg/kg) in soil at 0–20 cm depth under various land-use systems (Ram *et al.,* 2022)

Conclusion

The reviewed research suggests that agroforestry systems have a lot of potential for improving soil fertility. In comparison to monocropping, combining trees with agricultural crops increased N, P and K availability. Under tree-based land use patterns, there was an overall increase in SOC and carbon fractions. Also, under tree-based systems, an increase in soil organic matter boostedN and have a better micronutrient status in the soil than solo cropping systems and barren lands. So, adopting a tree-based farming system can be a sustainable way to reduce chemical fertilizer use, improve nutrient cycling, and increase soil carbon.

Conflict of interest

The authors declare that they have no conflict of interest.

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A Comprehensive insight into the phytoconstituents and health benefits of *Clematis* species

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ABSTRACT

The genus of *Clematis* is a buttercup family (Ranunculaceae), recognized for its flowers and adaptable as an ornamental plant in colder climates. **It contains around 300 species. *Clematis*** has a **variety** of active **phytoconstituents or secondary metabolites which are responsible for health benefits in human** beings. **Traditionally various species** of the ***clematis* genus** used for **centuries to treat various ailments including syphilis, bone disorders, gout, rheumatism, diuretics, wound healing, blood sugar control, blood diseases, spleen difficulties, leprosy, fevers, skin diseases. A systematic review of scientific electronic database and reference books were consulted to find all relevant literature for this work. This review discusses the** ethno-medicinal **usage, health advantages, phytoconstituents and bioactivities of *clematis* species.**

Introduction

Plants have served millions of people for centuries as their primary health care (Gakuya *et al.*, 2020). The majority of medicines used to cure ailments in various systems of traditional medicine are based on plants and their phytoconstituents. Secondary metabolites in plants not only participate in their endurance by producing attractants for pollinators, but also act as chemical defenses against herbivores and disease (Yanqun *et al.*, 2020). Traditional medicines are used in Ayurveda, Siddha, Unani and Homeopathic practice for healthiness and to diagnose, treat, and prevent physical or mental-related health problems (Salmerón-Manzano *et al.*, 2020). Plant-based remedies apply various source materials including roots, leaves, bark, fruits, essential oil, etc (Ekpo *et al.*, 2008; Rasool Hassan, 2012).The genus *Clematis* encompasses more than 300 taxonomically accepted species within the Ranunculaceae family; which are widely distributed throughout temperate as well as tropical regions worldwide, especially beyond the tropics in the northern hemisphere. Plants of the *Clematis* genus are woody, climbing vines (Kaur *et al.*, 2020). Various plant parts of the *Clematis* genus are used traditionally to treat gout, bone disorders, syphilis, rheumatism, diuretics and skin disorders (Alvarez *et al.*, 2003). It is also used to treat purulent wounds and ulcers. Biologically antibacterial, cytotoxicity (Ding *et al.*, 2009), antimycotic (Buzzini Pieroni, 2003), anticancer (L.-H. Yan *et al.*, 2009), anti-inflammatory (Park *et al.*, 2006), antifungal activity showed by active phytoconstituents or secondary metabolites present in the plants of the *clematis* genus (Y. Li *et al.*, 2009). Many secondary metabolites of *Clematis* genus, including alkaloids, glycosides, and saponins, have good therapeutic properties (Duke, 1985; Kingsbury, 1964; Turner Szczawinski, 1991). The scientific community will hopefully benefit from the knowledge gained from geographical, botanical, phytochemical, therapeutic

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and pharmacological perspectives to plan safer tests with bioactive mixtures.

Material and Methods

Scientific electronic databases and reference books were used to find all relevant literature for this work. Several databases, including "Plant List" and "Plants of the World Online", confirmed the plant's scientific name.

Results and Discussion

Botanical information

There are more than 300 species of vines that bear flowers in the genus *Clematis*, which is a segment of the buttercup family (Ranunculaceae); known for their flowers, they are adapted as ornamentals in colder climates. Woody climbers of the genus *Clematis* produce stunning, huge flower clusters that are often white; however, some species also produce crimson or violet flowers. More than 70 species are used traditionally in China (Ding *et al.*, 2009). *C. virginiana*, *C. cirrhosa*, *C. vitalba*, and *C. viticella* are some common species. *C. virginiana* (Old Man's Beard) is a trailing climber that usually provides shady shelter as it can grow up to 15 m taller than other plants; this species is native to North America. The leaves of the vine are opposite and divided into leafstalk and leaflets. Some species are shrubby like *C.recta* (European species), and creamy white flowers present bloom during July to September (Duke, 1985) ˉ(Ody, 1993).

Traditional medicinal uses

A well-known plant in the *Clematis* genus is *C. montana* of the Rannuculaceae family; found primarily in India, although it is also available in Pakistan, Nepal, Bhutan, and China. In North India, it is commonly known as Garol, Geor Bel, Kanguli, Kaunie-Bali. In Germany it is known as Berg-Walrebe; bjerg-skovranke in Danish; Himalayan clematis, Anemone *clematis* in English. This species is used in many nations to cure a variety of diseases and disorders because of its exceptional healing powers. This plant is traditionally used against various diseases such as syphilis, bone diseases, gout; rheumatism, diuretic and skin diseases (Rana *et al.*, 2015). The well-known perennial herb from East Asia is called *Clematis gouriana*. Locals use it extensively for wound healing, blood sugar control, blood diseases, spleen problems, leprosy and fevers; and herbal cream of leaves extract prepared to treat skin infection (Sheela, 2014). By inhaling the fumes of freshly crushed leaves, *C. glycinoids* DC. has long been used in Australia to relieve headaches and colds (R. W. Li *et al.*, 2003). *C. pickeringii* is used to treat respiratory problems, joint pain, fever, edema, infection, snakebite and other inflammatory diseases (Muthaura *et al.*, 2007). In Kenya, *C. brachiata* is broadly used in headaches, malaria, abdominal pain, skin disorders, toothaches, and sore throats. The whole flowering plant of *C. dioica* is used in Guatemala to treat gonorrhea (Caceres *et al.*, 1995). According to popular folklore in Turkish *C. flammna* flowering herbs are used as an anti-inflammatory remedy, such as for rheumatism, and to reduce fever (Yeșilada *et al.*, 1997). Roots of *C. mandshurica* native to Korea are used to treat arthritis problems (Park *et al.*, 2006). *C. terniflora* and *C. chinensis* roots are regarded as a substitute for traditional Chinese drugs like analgesic, diuretic, antitumor, rheumatic arthritis, laryngitis, skin and breast infection (Xu *et al.*, 1996). The root extract of *C. chinensis, C. mashurica* are used traditionally to treat joint pain. In China and the north of Burma, *C. armandii* is used to treat gynecological diseases and dermatoses. *C. chinensis* is a deciduous climber native to China, Japan, Taiwan and Vietnam; possesses health benefits and clinically, it is used in cardiovascular and cerebrovascular diseases, rheumatoid arthritis, ischemic necrosis of bone, osteo-hyperplasia and protrusion of intervertebral disc, bone disease and fracture (Shi *et al.*, 2007). *Clematis gouriana* is a woody climber found in tropical and subtropical forests of India, Nepal, and China; widely used for malaria, headache, psoriasis, wound healing and skin problems (Naika Krishna, 2007). *C. apiifolia DC* is well-known plant in South Korea, Japan, and China. In Korean traditional medicine this plant species is reported to be used in neuralgia, facial paralysis, rheumatoid arthritis, and toothache (Lee *et al.*, 2019). *C. aethusifolia* Turczb is a Mongolian medicinal plant; its leaf and stem are extensively used to care for joint pain, vomiting, and indigestion (Shi *et al.*, 2007). *C. lasiandra* native to China used in their traditional system of medicine due to its antitoxic, diuretic, analgesic, and antipyretic action (Tian *et al.*, 2013). Leaf extract of *C. chinensis* Osbeck has been widely used in joint pain, and sore throat in China (C. Peng *et al.*, 2012).

C. florida Thunb is used to treat rheumatic arthritis, diuretics, stomachache, and jaundice in China (Feng Zhang). The roots of *C. henryi* Oliv are used traditionally to treat gout, and arthritis in Tujja (Sun *et al.*, 2016).

Phytoconstituents of the Genus *Clematis*

Nowadays, phytopharmaceuticals play an important role in geomedicine, plant science, food science, cosmetics industry, nano-life science, pharmacology, toxicology, agro chemistry and so on**.** Isoprenoids compounds, alkaloids, glycosides, volatile oils, steroids, organic acids, and phenols are the diverse ingredients found in the plants of *Clematis* genus; triterpenoid saponins, flavonoids and their glucosides, and lignans are the primary constituents present in plant species of *Clematis* genus (Table 1). Bidesmosidic saponins of the oleanolic and hederagenin types are the major triterpenoid saponins present in *Clematis* species. Flavones, flavonols, flavanones, isoflavones, xanthones are the major flavonoids present in *Clematis* genus. Eupomatene lignans, cyclolignans, monoepoxy lignans, bisepoxy lignans, and lignanolides make up the majority of the lignans in *clematis* (F. Sun Yang, 2009).

Table 1: List of chemical constituents of various *Clematis* species

S. No.	*Clematis* species	Chemical Constituents	References
1.	*C. parviloba*	Aporphine alkaloids: α-magnoflorine and β-magnoflorine. Phenolic glycosides: 2-((E)-3-carboxybut-2-en-yl)-4-hydroxy-3-methyl-phenyl-O-beta-D-glucopyranoside, 4'-hydroxy-3'-methoxy-phenol-beta-D-[6-O-(4"-hydroxy-3",5"-dimethoxy-benzoate)], glucopyranoside, clemaparviloside A. Megastigmane glycosides: Linarionoside A, B, & C, staphylionoside. Lignan: Syringaresinol, medioresinol.	(Chen *et al.*, 2009; L. H. Yan *et al.*, 2009; Yan *et al.*, 2008; Yan *et al.*, 2010)
2.	*C. argentilucida*	Triterpenoid saponin: Cussonside, 3β-O-[β-D-ribopyranosyl-(1 → 3)-α-L-rhamnopyranosyl-(1 → 2)-α-L-arabinopyranosyl] hederagenin-11,13-dien-28-oic acid, and 3β-O-{β-D-ribopyranosyl-(1→ 3)-α-L-rhamnopyranosyl-(1 → 2)-[β-D-glucopyranosyl-(1 → 4)]-β-D-xylopyranosyl}oleanolic acid. Ursane triterpenoid, oleanane triterpenoid and taraxerane saponin.	(Mei Zhao *et al.*, 2014)
3.	*C. hirsuta*	Sterols and Terpenes: β-Amyrin, lupeol, β-sitosterol, oleanolic acid, stigmasterol, (S)- (+)-dihydro-5-(hydroxymethyl)-2(3H)-furanone and (s)-(-)-5-hydroxymethyl-2(5H)-furanone, anemonin, dihydro-4-hydroxyl-5-(hydroxymethyl)-2(3H)-furanone (2- deoxy-D-ribono-1,4-lactone), biophenol, glucose and sucrose.	(Abdel-Kader *et al.*, 2008), (Ameya *et al.*, 2022)
4.	*C. montana*	Hederagenin based saponin: Hederagenin-3-O-α-L-arabinopyranosyl (1-3)-α-L- rhamnopyranosyl (1-2)-α-L-arabinopyranoside. Saponin: (3-0-β-ribopyranosyl) (l-3)-α-rhamnopyranosyl (l-2)-α-arabinopyranosido-28-0-α-L-rhamnopyranosyl (l-4)-β-D-glucopyranosyl (l-6)-β-D-glucopyranoside, and (3-0-β-ribopyranosyl (l-3)-α-rhamnopyranosyl - (l-2)-a-arabinopyranoside. Oleanolic acid based biglycoside: Clemontanoside B, E & F.	(Thapliyal Bahuguna, 1993a) (Thapliyal Bahuguna, 1993b) (Thapliyal Bahuguna, 1994) (Lu *et al.*, 2014) (H. Peng *et al.*, 2009)
5.	*C. armandii*	Lignan: (7R, 8S)-9-acetyl-dehydrodiconiferyl alcohol. Flavanone glycoside: 5, 4′-dihydroxy-3′-methoxyflavanone-7-(6″-O-β-L-rhamnopyranosyl)-β-D-glucopyranoside.	(Yan *et al.*, 2007)

6.	*C. vitalba*.	Vitalboside, n-triacontan, n-nonacosan, ginnon, ginnol, β-sitosterol, chlorogenic acid, caffeic acid, colneleic acid, colnelenic acid.	(Ulubelen, 1970)
7.	*Clematis delavayi* var. *spines cens*	7-hydroxyl-4,6-dimethoxy-5- methylcoumarin, (*E*)-para- coumatic acid, coniferaldehyde, 4,6,7-trimethoxy -5-methylcoumarin.	(Y. Li *et al.*, 2009)
8.	*Clematis akebioides* (Maxim owicz) Veitch	Benzenoids, monoterpene glycoside, and triterpenoid saponin.	(Y.-M. Zhang *et al.*, 2019)
9.	*Clematis tangutica*	Triterpenoid saponin: Tanguticoside A & B, clematangoticosides, 3-O-α-L-arabinopyranosyl hederagenin 28-O-α-L-rhamnopyranosyl ester. Saponin: vitalboside B, β-hederin	(Min Zhao *et al.*, 2016) (Wei *et al.*, 2022)
10.	*C. heracleifolia*	Heracleifolianosides.	(Du *et al.*, 2003; Q. Zhang *et al.*, 2022)
11.	*Clematis lasiandra* Maxim	3-O-β-D-ribopyranosyl-(1 → 3)-*α*-L-rhamnopyranosyl-(1 → 2)-[β-D-glucopyranosyl-(1 → 4)]-β-D-xylopyranosyl hederagenin , 3-O-β-D-ribopyranosyl-(1 → 3)-*α*-L-rhamnopyranosyl-(1 → 2)-β-D-xylopyranosyl oleanolic acid 28-O-β -D-glucopyranosyl ester, 3-O-β-D-ribopyranosyl-(1 → 3)-*α*-L-rhamnopyranosyl-(1 → 2)-β-D-xylopyranosyl hederagenin, and 3-O- β-D - ribopyranosyl-(1 → 3)-*α*-L-rhamnopyranosyl-(1 → 2)-[β-D-glucopyranosyl -(1 → 4)]-*α*-L-arabinopyranosyl hederagenin.	(Tian *et al.*, 2013)
12.	*Clematis chinensis*	Clematochinenoside H-K, mandshunoside-B, 3-O-β-d-ribopyranosyl-(1 → 3)-α-l-rhamnopyranosyl-(1→2)-[β-d-glucopyranosyl-(1→4)]-α-l-arabinopyranosyl oleanolic acid28-O-α-l-rhamnopyranosyl-(1→4)-β-d-glucopyranosyl-(1→6)-β-d-glucopyranoside,3-O-β-d-xylopyranosyl-(1→ 2)-α-l-arabinopyranosyl hederagenin 28-O-α-l-rhamnopyranosyl-(1→4)-β-d-glucopyranosyl-(1→6)-β-d-glucopyranoside, clematichinenoside A .	(Fu *et al.*, 2017)
13.	*Clematis ganpiniana*	Clematiganoside-A ,3β-[(α-L-arabinopyranosyl)-oxy]olean-12-en-28-oic acid, hederagenin 3β-O-α-L-arabinopyranoside, 3β-O-α-L-rhamnopyranosyl-(1→2)-α-L-arabinopyranosyl oleanolic acid , α-hederin.	(Ding *et al.*, 2009; F. Sun *et al.*, 2007)
14.	*Clematis viticella*	flavonoid: Isoorientin, isoorientin 3′-O-methyl ether, quercetin 7-O-α-L-rhamnopyranoside, quercetin 3,7-di-O-α-L-rhamnopyranoside, manghaslin and chrysoeriol 7-O-β-D-glucopyranoside. Phenolic acids: Caffeic acid, (E)-p-coumaric acid and p-hydroxybenzoic acid.	(Kırmızıbekmez *et al.*, 2019)
15.	*Clematis Gouriana*	Alkaloids, carbohydrates, steroids, saponins, tanins, flavonoids, phenolic compounds, and terpeniods.	(Sheela, 2014)
16.	*Clematis parviloba*	Aporphine alkaloid: β-magnoflorine, α-magnoflorine.	(Chen *et al.*, 2009)
17.	*C. orientalis*	Resorcinol	(Karimi *et al.*, 2018)
18.	*C. ispahanica.*	Ellagic acid	(Karimi *et al.*, 2018)
19.	*Clematis grata*	Clematoside-S,hederagenin-3-O-β-F-ribopyranosyl (1→3)-α-L-rhamnopyranosyl(1→2)-α-L-arabino-pyranoside.	(Sati *et al.*, 1990)

20.	*Clematis akebioides* (Maximowicz) Veitch	Benzenoids, monoterpene glycoside, and triterpenoid saponins.	(Y.-M. Zhang *et al.*, 2019)
21.	*Clematis mandshurica*	Triterpene saponin: mandshunosides C–E	(L. Li *et al.*, 2013)

Conclusion

Clematis species are widely used around the world for their known health benefits. They have analgesic, diuretic, anti-cancer and anti-rheumatic properties. These numerous biological activities are carried out by various chemicals, the main components of which include saponins, flavonoids, and lignin and ranunculin glycosides. *Clematis* has great potential for human health and its medicinal effects should be studied more closely and thoroughly. There is a need for preclinical and clinical research into the use of these plants, as well as more detailed studies of all bioactive phytoconstituents and their mechanisms at the cellular and tissue levels.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Sustainable utilization of biogas technology: A promising solution to combat the energy crisis in India

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ABSTRACT

India is facing a significant energy crisis due to its rapidly growing population, which is not being met by an equivalent increase in energy supply. According to the US Energy Information Administration, India's electricity consumption is projected to grow by 3.3% annually until 2035. Biogas technology, which converts waste into clean energy, offers a promising solution to this problem and accounts for 9% of global energy consumption. Despite being introduced in 1981, biogas technology's potential in India remains largely untapped, with only 7.34 MWe of off-grid projects generated by 2020. However, Tamil Nadu and Karnataka have significant potential for biogas generation. The National Biogas and Manure Management Program (NBMMP) have installed 5,056,139 biogas plants between 1981-82 and 2020-21, with Maharashtra being the top performer. India's agrarian economy provides ample raw materials for biogas generation, making it a crucial renewable resource for the country's energy crisis. Given the pressing need to address global warming, greenhouse effects, depleting fossil fuels, and pollution, biogas technology is essential for a cleaner, more sustainable future. Focusing on biogas technology can help India meet its increasing energy demands and contribute to a cleaner and more sustainable future. From 2018-19 to 2020-21, the NBMMP received a total allocation of INR 1,439,249,000.

Introduction

Energy plays a crucial role in the development of any nation, and per capita energy consumption is a key indicator of socioeconomic progress (Omer, 2017). Efficient utilization of energy services is essential for poverty alleviation, as no government can significantly address poverty without such services (Rao *et al.,* 2009). In India, energy demand is rising, and the country's massive population exacerbates this situation. This escalating demand has created an energy crisis, calling for the exploration of renewable energy sources with multiple environmental benefits, such as maximizing locally available resources, efficiency, job creation, and reducing greenhouse gas emissions (Rajendran, *et al*., 2012). Biogas is a clean fuel with several advantages compared to fossil fuels and untreated biomass (Pathak, *et al.,* 2009). India, an agrarian country with more than 70% of its population living in villages, has abundant raw materials accessible for biogas generation. However, despite its potential, the adoption rate of biogas technology in India remains low. Currently, India has a biogas production capacity of 2.07 billion m^3/year (Mittal, *et al*., 2018).

In the early 1970s, India launched several programs to distribute biogas technology. By 2017, India achieved an overall energy sufficiency of 63%, but electricity shortages are still common, although India is the 4th largest producer of electricity worldwide (Minde *et al.,* 2013). Biogas is one of the most effective substitutes for reducing greenhouse gas emissions, indoor air pollution, and global climate change (Pathak *et al.,* 2009). According to the researchers Sharma and Neema (2013) biogas has greenhouse reduction potential upto 262.5 kg CO_2/day and 6.25 kg CH_4/day and can save approximately 6 LPG cylinders and 2850 kg wood/year by installing 2m^3 capacity of biogas plant for 4 person. Additionally, biogas digestate can be utilized, as shown in Table 1.

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The total number of biogas plants established in India under the National Biogas and Management Program (NBMMP) from 1981-1982 to 2020-2021 as of June 30, 2020, is shown by the following state:

States/UTs	No. of Biogas Plants
West Bengal	1105
Uttarakhand	364582
Uttar Pradesh	440930
Tripura	3710
Telangana	19702
Tamil Nadu	223894
Sikkim	9044
Rajasthan	72446
Punjab	185998
Puducherry	17541
Odisha	271809
Nagaland	7953
Mizoram	5856
Meghalaya	10659
Manipur	2128
Maharashtra	**924111**
Madhya Pradesh	376558
Kerala	153203
Karnataka	510916
Jharkhand	7823
Jammu and Kashmir	3200
Himachal Pradesh	47706
Haryana	63433
Gujarat	435272
Goa	4226
Delhi	578
Dadra and Nagar Haveli	681
Chhattisgarh	59850
Chandigarh	169
Bihar	129925
Assam	138483
Arunachal Pradesh	3609
Andhra Pradesh	558962
Andaman and Nicobar Islands	97
India	**5056159**

*Source: Rajya Sabha Unstarred Question No. 1095, dated 20.09.2020 Downloaded from:http://www.indiastat.com/table/power-data/26/biomass/452705/1383399/data.aspx

organic fertilizers and amendments to increase soil fertility while avoiding the harmful impacts of artificial fertilizers. In 1981, the Indian government established the National Programme on Biogas Development to offer rural communities environmentally sustainable options for improving their quality of life.

Despite the government's efforts, the rate of biogas distribution in rural households remains low, and there is a need to explore the progress made toward biogas development and the cash raised for state biogas development. The National Biogas and Management Management Programme is a Central Government Scheme that provides subsidies to rural and semiurban households to establish family biogas units. As per Table (1), 5056159 biogas plants were found under the NBMMP in India, with Maharashtra having the most, followed by Andhra Pradesh, Karnataka, Uttar Pradesh, and Gujarat. From 2018-19 to 2020-21, India's National Biogas and Manure Management Programme (NBMMP) received total funding from Rs. 14 39, 24,900/- (table 2).

Given the urgent need to address global warming, greenhouse effects, fossil fuel depletion, and pollution, biogas technology is a crucial renewable resource and a key solution for India's energy crisis. Focusing on biogas technology can help India meet its increasing energy demands while contributing to a cleaner, more sustainable future. The National Biogas and Manure Management Programme (NBMMP) was founded in India in 1981 to improve the quality of life in rural areas through environmentally friendly choices and to reduce the energy crisis in rural areas (Milieu en Natuur Planbureau and Shukla, 2007).One of the program's key goals is to reduce the usage of LPG and other conventional fuels by producing clean biogas that may be used for cooking. This is accomplished by establishing family biogas units in rural and semiurban homes using central government subsidies supplied through the NBMMP scheme. In addition to offering an alternate fuel source, the programme intends to meet the Integrated Energy Policy's lifetime energy demands for cooking.

Another important goal is to supply organic biogas manure to reduce the need for chemical fertilizers, which are harmful to the environment. This organic manure can be used to boost crop output and soil fertility, resulting in more sustainable agricultural practices (Khoiyangbam, 2011). The programme also aims to reduce the strain on forests and the hard work of rural women.

Table 2: Funds allotted to selected states under India's National Biogas and Manure Management Programme (NBMMP) (2018-2019 to 2020-2021-up to 31.08.2020)

Amount in Rs			
State/City	**2018-2019**	**2019-2020**	**2020-2021-upto 31.08.2020**
Andhra Pradesh	36019890	37350338	27901400
Chhattisgarh	24473397	24917666	0
Gujarat (NDDB)	0	24000000	12000000
Haryana	6600000	0	0
Karnataka	106269050	36684000	42000000
Kerala	2393812	14631994	0
KVIC, Mumbai	60626136	30736748	0
Madhya Pradesh	46128729	39907500	39952500
Maharashtra	42000000	54000000	0
Meghalaya	1250000	0	0
Odisha	8267000	4800000	972000
Punjab	38159298	33487208	21099000
Rajasthan	14700000	0	0
Tripura	2203150	3365000	0
Uttar Pradesh	4740100	0	0
Uttarakhand	3600000	18260000	0
India	**397430562**	**322140454**	**143924900**

Source: Rajya Sabha Unstarred Questions No. 1095, dated 20.09.2020. Downloaded from: http://www.indiastat.com/table/power-data/26/biomass-biogas/452705/1383402/data.aspx

who are frequently required to collect firewood for cooking. The programme helps to maintain trees and alleviate the strain on rural women by reducing their reliance on firewood (Gautam *et al*., 2009 and Liu *et al.,* 2008). The NBMMP also aims to enhance rural sanitary conditions by linking hygienic toilets to biogas plants, which can assist in addressing the issue of open defecation in rural regions. This link also allows for the creation of biogas from human waste, which helps to reduce carbon and methane emissions, both of which contribute significantly to climate change.
As stated in Table 3, the government has made concerted efforts to promote biogas growth in both rural and urban regions by providing subsidies and executing various programmes. Under the NBMMP scheme, these efforts have resulted in the building of a substantial number of biogas plants in India, with Maharashtra leading the way. Despite the tremendous potential for biogas generation in India, the adoption of this technology is still limited, particularly among rural households. As a result, ongoing efforts are required to promote and scale up biogas technology in India to meet rising energy demands while reducing the environmental impact of traditional fuel sources. As of 2020, 5056159 biogas units with capacities ranging from 1 to 25 M3/day were erected under the New National Biogas and Organic Manure Management Programme. The details are presented in Table no. 3. The funds granted by the Central Financial Assistance for developing renewable energy schemes in India are shown in Table no. 5. The NBMMP provides a category-specific subsidy for the installation of household biogas plants with capacities ranging from 1-6 m3/day:

- For the general category-Rs 9000/plant
- For SC and ST-Rs, 11,000/plant
- Latrine-attached R chromosome 12,000/plant

Economics of family-sized biogas plants in India
According to the findings of Pathak *et al.* (2009), a small family-sized biogas plant has the potential to mitigate global warming by 907/t CO_2 equivalent/year at a cost of US $10/t CO_2 equivalent, earning a carbon credit of US $97/year under the Clean Development Mechanism (CDM). Four calves in a home biogas plant may generate 4,400 kilograms of manure (dry weight) and 2,200 cubic meters of biogas per year, eliminating the need for 316 liters of kerosene, 5,535 kilograms of firewood and 10,571 kilograms of CO_2 equivalent. Approximately 1,275 kilograms of carbon may be replaced by biogas slurry created from the waste of four calves in place of 62 kg of nitrogen, 28 kg of phosphorus, and 85 kg of potassium. Additionally, methane is 21 times more aggressive than CO_2; thus, animal dung management can prevent the emission of methane gas (Yua *et al.,* 2008). Biogas can be a good substitute for fossil fuels and greatly contributes to the available energy needed for heating and cooking (Nasery, 2011; Gautam *et al*., 2009). There are 335 million tons of manure produced annually in India, 225 million of which are usable for biogas. India can earn $4,818.7 million annually in carbon credits by recycling this material, which is enough to power 51.2 million family-sized biogas plants and reduce annual global warming by 496 million tons of CO_2 equivalent.

Table 3: Biogas development in India

Year	Policies Implemented
1981	• The first biogas development program, known as NPBD, was launched. • A capital subsidy was provided under this program for the installation of small-scale biogas facilities. • One of the criteria for receiving the capital subsidy under this NPBD was owning 2-3 cattle.
1995	• Energy recovery from municipal, agricultural, and industrial wastes is the focus of NPBD, a nationwide initiative.
2006	• National Biogas and Manure Management Programme (NBMMP) is a government initiative with the same goals as NPBD, thus it was renamed after the Ministry of New and Renewable Energy (MNRE). • To promote decentralized electricity as an option in rural regions (3kw to 250kw), the MNRE has this year established an off-grid biogas power-generating scheme. • The development of a biogas power plant and the production of bio-CNG using biomethanation technology have both received funding support.
2016	• In 2000, the Ministry of Environment and Forest (MoEF) increased its authority and subsequently in 2016, revised its guidelines for solid waste management and disposal. • A new tariff policy mandated by the federal government mandates that all electricity supplied by electrical distribution companies be produced entirely from garbage. • The general tariff for electricity produced by waste-to-energy plants has been announced by the Ministry of Power.

Table 4: **Number of Biogas Plants (1-25M3 Per Day) Installed in India Under the New National Biogas and Organic Manure Programme (As of June 2020)**

States/UTs	Small Biogas Plants Established (up to June 2020)
West Bengal	1105
Uttarakhand	364582
Uttar Pradesh	440930
Tripura	3710
Telangana	19702
Tamil Nadu	223894
Sikkim	9044
Rajasthan	72446
Punjab	185998
Puducherry	17541
Odisha	271809
Nagaland	7953
Mizoram	5856
Meghalaya	10659
Manipur	2128
Maharashtra	**924111**
Madhya Pradesh	376558
Kerala	153203
Karnataka	510916
Jharkhand	7823
Jammu and Kashmir	3200
Himachal Pradesh	47706
Haryana	63433
Gujarat	435272
Goa	4226
Delhi	578
Dadra and Nagar Haveli	681
Chhattisgarh	59850
Chandigarh	169
Bihar	129925
Assam	138483
Arunachal Pradesh	3609
Andhra Pradesh	558962
Andaman and Nicobar Islands	97
India	**5056159**

Sources: Lok Sabha Unstarred Question No. 1979, dated 22.09.2020 Downloaded from: http://www.indiastat.com/table/power-data/26/biomass-biogas/452705/1378511/data.aspx

Table 5: Central finance assistance funds for the renewable energy scheme

SN	Year	funds sanctioned
1.	2016 -17	4307 crore
2.	2017-18	4080 crore
3.	2018 -19	5146.63 crore
4.	2019-20	3891.74 crore

There are annual savings of 5,535 kg of firewood, 4,400 kg of cattle dung cake and 316 L of kerosene when a family-sized biogas system is used instead. Compared to burning firewood, heating with calf dung cake reduces yearly emissions by 3.5-12.2 kg of NOx, 3.9-6.2 kg of SO_2, 436.9-549.6 kg of CO, and 30.8-38.7 kg of volatile organic compounds. The yearly emission savings for a biogas system that serves a single household are 16.4 kg of nitrogen oxides, 11.3 kg of sulfur dioxide, 987.0 kg of carbon monoxide, and 69.7 kg of volatile organic compounds. The State of Assam in India has approximately 85,000 family-type biogas plants, according to the National Biogas and Manure Management Programme (NBMMP). Farmers who own biogas plants are more likely to use organic agricultural methods, which is a major contribution to long-term sustainability. With 2,828 out of 85,346 hectares under organic cultivation in the North East (Hazarika *et al.,* 2015), organic farming has become a major focus in Assam's agricultural sector. A survey of rural communities in Sirsi, Karnataka, South India, revealed that 43% had access to dung supplies for operating biogas plants, while 65% had constructed such plants. All the biogas plants are running, and 85% of families with biogas use it to satisfy their cooking energy needs, improving women's lives everywhere.

Conclusion

India launched its biogas development plan in 1981 to address the country's energy shortage in rural areas, fuelled by concerns about global warming and improper garbage disposal. For the sustainable use of energy resources, policymakers should promote the installation of biogas facilities by making them economically viable through carbon market mechanisms. Biogas technology can alleviate the need for firewood, help with indoor air pollution control, and provide low-cost lighting. Biogas also slows deforestation, soil degradation, flooding, and desertification because less of the world's forest cover is used for electricity at home. The byproduct of valuable manure benefits soil health and crop yield and generates cash for the rural population. The biogas project is expected to provide numerous local jobs, including the experts needed to construct methane digesters that can

benefit regional businesses. It also frees women's time and effort in tasks such as gathering fuelwood and preparing meals, improving soil quality, increasing agricultural output, and reducing costs compared with chemical fertilizers. The carbon market offers India the global potential to address the energy crisis and generate new revenue. Carbon revenues generated by industry can encourage farmers to develop biogas as a profitable activity while combating climate change. Repurposing biomass into cleaner and greener technologies in rural areas could lead to an improved standard of living, a healthier local environment, and a decreased global warming potential.

Conflict of interest

The authors declare that they have no conflicts of interest.

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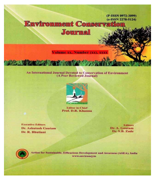

Estimating crop water requirement in Madhya Pradesh's agro climatic regions: A CROPWAT and CLIMWAT software case study

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ABSTRACT

Estimating actual crop evapotranspiration is vital in water-scarce environment affected by climate change, particularly for optimizing irrigation and enhancing crop yield. This research focuses on assessing crop water and irrigation requirement for major crops across six districts of Madhya Pradesh, India, spanning diverse agro-climatic regions. Employing CLIMWAT 2.0 and CROPWAT 8.0 software, calculated crop evapotranspiration and devised irrigation strategies tailored to local climatic conditions. The FAO-Penman-Montieth (FAO-PM) equation for reference evapotranspiration (ET_0), aiding in crop water requirement computation and irrigation planning. Our findings reveal substantial variations in crop water requirements across crops and districts. For instance, soybean in Indore requires the highest water input at 380 mm, while in Guna, was least at 303 mm. Wheat, on the other hand, register the highest water needs in Khandwa at 510.6 mm and the lowest in the Neemuch district at 370.8 mm, particularly during the *rabi* season. Besides that, this study underscores the need for district-specific considerations, taking into account climate and soil characteristics when formulating water management strategies. Employing efficient irrigation practices and techniques to manage water stress becomes imperative for optimizing crop yield and achieving economic returns. Implementing customized approaches to enhance water use efficiency and promote sustainability in agricultural production is crucial. These research outcomes provide valuable insights for policymakers, agricultural practitioners, and water resource managers to develop context-specific water management strategies.

Introduction

Water, a precious and scarce natural resource, is essential to life, livelihood, food security, and long-term sustainable development. "Potential changes in climate can impact agriculture and water resources" (Ludwig *et al.*, 2014). With the prolonged drought, declining water level in dams, sedimentation of rivers, and water restrictions due to constant competition from other sectors, the need for judicious use of available water for sustainable development of agriculture. Agriculture consumes

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the most water in India (81 per cent); thus, making the most effective use of water in agriculture should be a top focus (Surendran *et al..,* 2013; Dhawan, 2017; Kumar and Gautam, 2014). Soil moisture comprises a little portion (0.15%) of the world's available freshwater (Dobriyal *et al..,* 2012). The water available in the form of soil moisture is used to help produce crops and support plant growth. Management of soil water is critical to numerous hydrological, ecological, and biogeochemical activities. For effective resource planning, accurate information on evapotranspiration, crop water requirements, and net irrigation requirements is essential (Levidow *et al..,* 2014). As a result, profitability and long-term viability might improve. Effective water resources management impact agricultural productivity, water usage efficiency, and reduces the negative impact on the environment through nutrient leaching, eutrophication, waterlogging, and pollution of surface and groundwater (Scanlon *et al..,* 2007).“Crop water requirement (CWR) is defined as the depth of water (millimetres) required to meet the water consumed by evapotranspiration (ET_c) by a disease-free crop growing in fields under non-restrictive soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment”. Accurate CWR estimation is a vital part of proper water management in agriculture. Such assessment requires specific instrumentation and methodologies (Rafeet, 2002). The most common criteria for assessing CWR are currently based on the climatic water balance (i.e., evapotranspiration, lysimeter), plant physiological properties, soil water status measurements, remote sensing, surface energy balance algorithm, or a combination of these factors (Gaddikeri *et al.*., 2022). Where meteorological data are available, assessing the CWR is based on the atmospheric water demand called reference evapotranspiration (ET_0) is used. Under limited weather data condition, CROPWAT may used for assessing the ETo, crop water requirement and irrigation scheduling. It is a decision support tool developed by the Land and Water development division of the Food and Agriculture Organization (FAO). CROPWAT is a computer-based software that calculate agricultural water and irrigation needs based on soil, climate, and crop data. CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT. Besides, both the software combinedly used to develop irrigation practice guidelines, the creation of irrigation schedule under diverse water allocation needs, and estimates under rainfed or shortfall irrigation situations. Khan *et al..,* 2021 applied CROPWAT software in the Al-Qassim Province, Saudi Arabia, to estimate the topographical sustainability of the crop water requirement. Furthermore, they explored the utility of CROPWAT and CLIMWAT software for irrigation scheduling of the main crops. Several studies were conducted using CROPWAT software for estimation of crop water requirements for various purposes like evaluating the performance of canal command system (Rajput *et al..,*2017;Vibhute *et al..,* 2016), estimating the potential command area of pulp and paper mill effluent (Rajput *et al..,* 2021), Irrigation scheduling (Prattoyee *et al..,* 2021; Rahman and Sarma, 2019; Ratnaraju *et al..,* 2016), deficit irrigation scheduling (Diro and Tilahun, 2009), climate change impact on crop water (Naik *et al..,* 2015), and water footprint studies (Ewaid *et al..,* 2019) and Reference evapotranspiration modelling (Pawar *et al..,* 2021). CROPWAT uses meteorological data from over 5000 climate stations worldwide to crop water requirements, and helps in crop planning. The CLIMWAT provides data for estimating ET_0, including daily maximum (Tmax) and minimum temperatures (Tmin), relative humidity (RH), daylight hours/solar radiations (SR), wind speed (WS), and precipitation (P). In the CROPWAT model, the FAO-Penman Monteith equation was used to estimate ET_0 using data from the CLIMWAT. Using this data, an attempt was made to estimate crop water requirements of main crops in Madhya Pradesh's Agro-climatic zones using long-term climatic data and developing strategies for the appropriate use of existing water resources.

Material and Methods

The detailed methodology of data collection, its analysis and application of the model to the study area have been discussed in the following heads:

Study Area

The research was carried out in the Indian state of Madhya Pradesh. This includes the districts of Bhopal, Guna, Indore, Khandwa, Neemach, and

Sagar. Table 1 displays the geographic coordinates of the districts and its agro-climatic zones. The location map of the study area is given in Figure 1. Madhya Pradesh rainfall varies significantly, and the climate ranges from sub-humid in the central region to semi-arid in the north. According to all six meteorological station observations, a hot, dry summer lasts from April to June, followed by monsoon rains, with average monthly rainfall increasing dramatically from mid-June to mid-September (Figure 2). And the winter months (November to February) are cool and dry. As a result, the temperature fluctuates from 33°C to 44°C in the summer and 10°C to 27°C in the winter. Furthermore, relative humidity was at its lowest in May and June. The various climatic parameters and ET_0 values for selected districts are presented in Table 2.

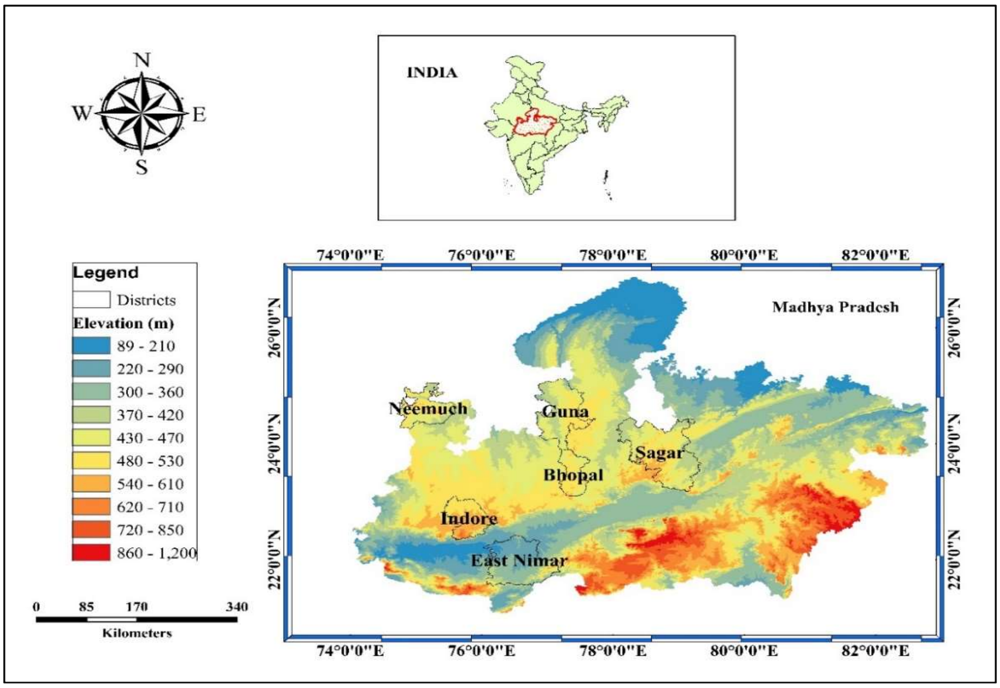

Figure 1: The location map of the study area districts.

Table 1: The geographical information as well as the agro-climatic zone of the study area

SN	Meteorological Station	Latitude (N)	Longitude (E)	Altitude (m)	Agro-climatic Zone
1	Bhopal	$23^0$15'35	77^0 24'45	427	Malwa Plateau (46%) and Vindhya Plateau (42%)
2	Guna	24^0 34'	77^0 21'E	474	Gird Zone
3	Indore	22 ^{0} 43'31	75 ^{0} 51' 56	602	Malawi plateau Agro-climatic
4	Khandwa (East Nimar)	24^0 00'10	80^0 42'56	432	Nimar valley Agro climatic
5	Neemuch	24°27'55	74°52'15	534	Malwa plateau
6	Sagar	23° 10'	78° 40'	810	Vindhya Plateau

Table 2: Average climatic data in the study region

District	Tmin (^{0}C)	Tmax (^{0}C)	RH (%)	A.A.R. (mm)	WS (m/s)	SR (MJ/m²/day)	ET_0 (mm/day)
Bhopal	18.5	31.5	47	1099	1.7	18.7	4.65
Guna	17.6	31.8	49	1116	1.43	18.4	4.35
Indore	17.9	31.9	48	980	3.19	18.6	5.67
Khandwa	19.6	33.6	46	948	2.04	18.8	5.2
Nimuch	18.6	31.5	44	870	1.81	17.8	4.67
Sagar	19.5	31.1	46	1218	1.75	18.5	4.73

(Note: Tmin: Minimum Temperature, Tmax: Maximum temperature, RH: Relative Humidity, A.A.R.: Average Annual Rainfall, WS: Wind Speed, SR: Solar Radiation)

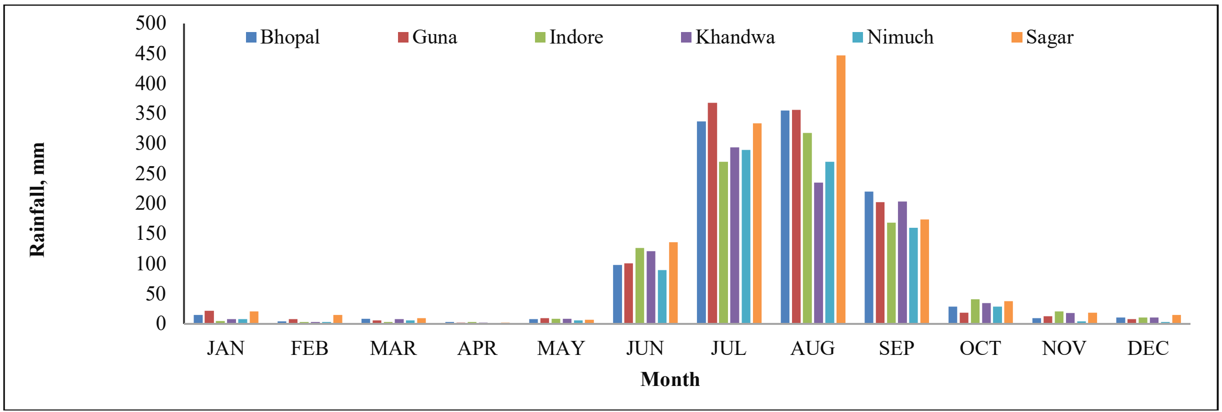

Figure 2: Monthly rainfall received in different districts

Data collection

Daily meteorological data such as rainfall, Tmax, Tmin, RH, and SR, WS information were collected from the CLIMWAT 2.0 software for several districts in MP over a 30-year period. These were utilized to compute the reference evapotranspiration. The principal crop planted in each area was considered when estimating crop water requirement, irrigation scheduling, and water management. Figure 3: Monthly effective rainfall received in different districts. The data needed for the CROPWAT 8.0 model as input, such as date of sowing, development stages and its crop coefficients, harvesting date, and duration of crops, were obtained from ICAR and FAO (Allen *et al.*., 1998) published reports. Average annual rainfall in the districts varied from 870 mm (Neemuch district) to 1278 mm (Sagar district). District wise, effective rainfall obtained were 631.1, 630.1, 625.5, 627, 560.5, and 682.5 mm for Bhopal, Guna, Indore, Khandwa, Neemuch, and Sagar, respectively.

Crop water requirement estimation

Crop water requirements were estimated using climatic parameters, crop, and soil parameters (FAO, 2009; George *et al.*., 2000). The crop coefficient and reference evapotranspiration value are the major factors influencing CWR values. Using climatological data, reference evapotranspiration was computed using an FAO-PM equation and multiplied by crop coefficient to get actual crop evapotranspiration (ET_C). The major soil and crop grown in the study regions are presented in the Table 3 and 4. Reference crop evapotranspiration (ET_0) represents the amount of water that a theoretical grass reference crop would release through a combination of evaporation and transpiration. This reference crop is envisioned with consistent attributes, including a height of 0.12 meters, a surface resistance of 70 s m^{-1}, and an albedo of 0.23. Alfalfa grass is considered to be the reference crop for ET estimation (Allen *et al.*.,1998). Firstly, the FAO-Penman Monteith equation (Equation 1.) was used to determine the ET_0 using the CROPWAT 8.0 model based on FAO Irrigation and Drainage Paper 56. The FAO-PM equation necessitates climatic data, including Tmax, Tmin, RH, SR, and WS, for the estimation of ET0..

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.3u_2)} \qquad \ldots\ldots..1$$

Where,
Rn is net solar radiation (MJ m^{-2} day^{-1})
λ is the latent heat of evaporation (MJ kg^{-1})
T is the daily mean temperature (°C)
U_2 is the mean daily wind speed at 2meter height (m/s)
$e_s and e_a$- Saturation and actual vapour pressure (kPa)
G - Soil heat flux (MJ m^{-2} day^{-1})
Δ-the slope of saturated water vapor pressure curve (kPa/c)

The actual crop evapotranspiration of different crops can be determined through the Equation. 2.

$$ET_c = Kc * ET_0 \qquad \ldots\ldots..2$$

where, ET_c, actual crop evapotranspiration; ET_0, reference crop evapotranspiration; Kc = crop coefficient.

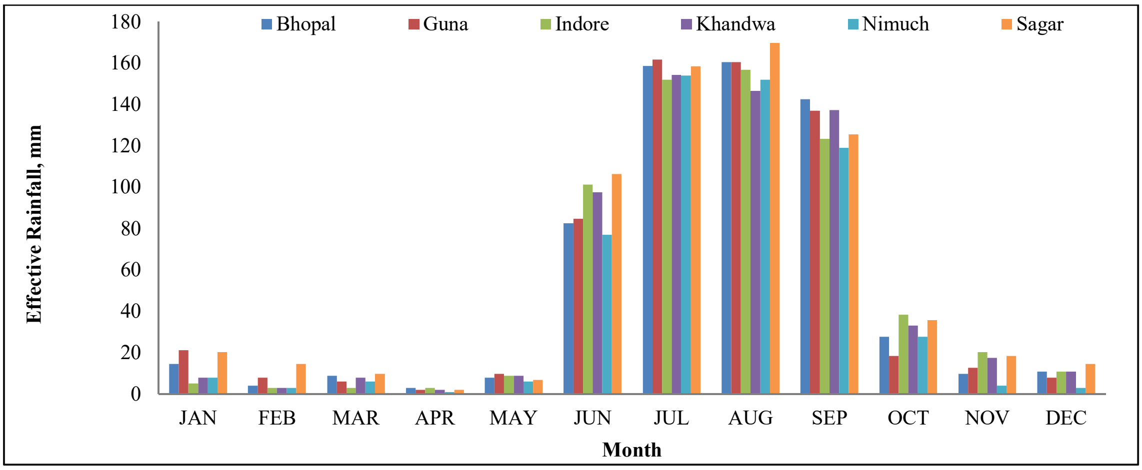

Figure 3: Monthly effective rainfall received in different districts.

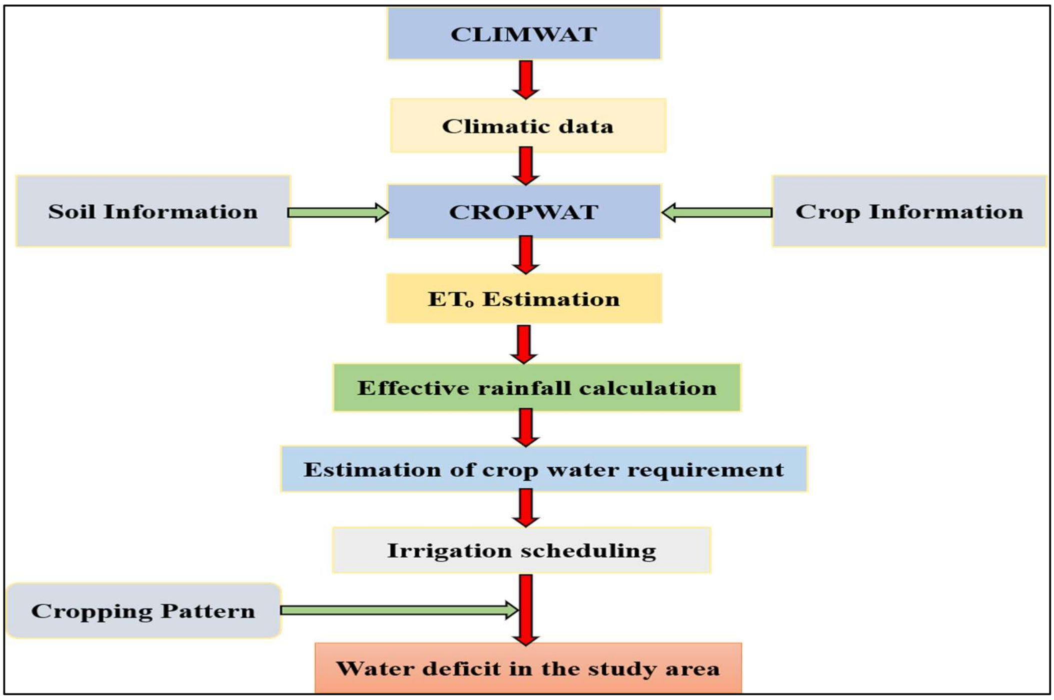

Figure 4: CROPWAT model flow chart for calculating crop water requirements

CROPWAT model uses soil, climate, and crop information as input factors. Furthermore, the soil water balance equation was used to estimate the seasonal crop water requirement on a daily basis. The flow chart (Figure 4) depicts the entire approach for estimating crop water with CROPWAT. The major crops cultivated in the study area are soybean, wheat, chickpea, maize, paddy, mustard, lentil, cotton, green gram, sunflower, and sorghum. The Kc values used to estimate ET_c from ET_0 for major crops grown in the study area were derived from the literature (Allen *et al..*, 1998; Doorenbos and Pruitt, 1977). The Kc for the crop will vary over the growing period, which can be divided into four distinct stages: initial, crop development, mid-season, and late season. Hence ET_c simultaneously varies with crop growth stages. The details of the crop coefficients for the major crops grown in the study districts are presented in Table 5.

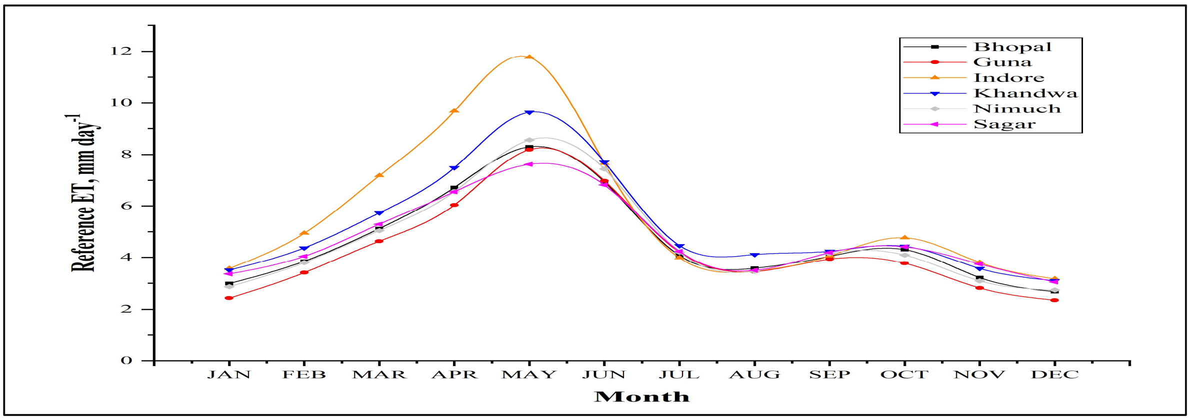

Figure 5: Reference evapotranspiration (ET_0) variation in different districts

Table 3: Major soil and crops grown in study regions

SN	Districts	Major Soil	Major Crops
1	Bhopal	Medium Black	Soybean, Wheat, Gram
2	Guna	Medium and Deep Black	Jowar, Maize, Soybean, Wheat, Gram, Mustard
3	Indore	Medium Black	Soybean, Wheat, Gram
4	Khandwa	Medium Black	Jowar, Soybean, Wheat, Gram, Cotton
5	Neemach	Medium Black	Maize, Soybean, Wheat, Gram, Mustard
6	Sagar	Medium and Deep Black	Urd, Soybean, Wheat, Gram, Lentil

Source:DoLR.gov.in(chrome-extension://oemmndcbldboiebfnladdacbdfmadadm/https://dolr.gov.in/sites/default/files/Madhya%20Pradesh_SPSP.pdf)

Table 4. Water Requirement of various crop in MP districts

SN	Crop	Crop water requirement (cm)
1	Soybean	45-70
2	Wheat	45-65
3	Gram	40-50
4	Rice	120-160
5	Maize	50-80
6	Jowar	45-55
7	Mustard	30-40
8	Cotton	70-130

Source: http://www.angrau.ac.in/media/7380/agro201.pdf

Table 5: Details of the crop coefficients for the major crops

Sl. No	Crop	Max root depth (m)	Kc values of the crop at different stages		
			Initial	Mid	Final
1	Wheat	1	0.3	1.15	0.25
2	Soybean	0.6	0.4	1.15	0.5
3	Chickpea	0.6	0.4	1	0.35
4	Maize	1	0.45	1.11	0.95
5	Lentil	0.6	0.4	1.1	0.3
6	Sunflower	0.80	0.52	1.11	0.41
7	Mustard	1	0.35	1.15	0.35
8	Sorghum	1	0.3	1.05	0.55
9	Cotton	1	0.5	1.15	0.65
10	Green gram	0.6	0.27	1.1	0.67

Net irrigation requirement (NIWR):
The water that must be given via the irrigation system to ensure that the crop receives its complete water requirements is NIWR. If irrigation water is the only source of water supply for the plant, the irrigation need must be larger than the crop water requirement to ensure irrigation system efficiency. However, if the crop gets part of its water from rainfall, deep seepage, the demand for irrigation water will be slightly lower than the demand for crop water.
Therefore, NIWR is calculated as,

NIWR = ET_c - Effective rainfall (ER)

For this study, effective rainfall was computed according to the "USDA Soil Conservation Services Method" using CROPWAT 8.0 model on a monthly basis using the following criteria (USDA, 1967),
1) If total rainfall is less than 250 mm, then ER is given by the following equation

ER=Total Rainfall (TR)*(125-0.2*Total Rainfall) / 125

2) If total rainfall is more than 250 mm, ER is given by the following equation;

ER=125+0.1 * Total Rainfall

Results and Discussion

Reference evapotranspiration variation

There was variation in the ET_0 among districts. It begins to rise in January and reaches a peak in May. Also, from July through August, ET_0 rises and peaks in October then falls and reaches its lowest point in December. ET_0 was greatest in the Indore district and lowest in the Guna district. Figure 5. depicts the variation in theET_0in different months in selected districts.

Crop evapotranspiration of Major crops in the Bhopal districts

The results of decadal ET_c, ER and irrigation requirement (IR) for the major *Kharif* and *Rabi* crops cultivated in the Bhopal district have been shown in Tables 6-9. The seasonal crop water requirement of soybean was determined to be 367.8 mm, while the total effective rainfall received throughout the growing soybean season was 420.4 mm. A significant proportion of crop water demand is met by effective rainfall, but delayed sowing results in a shortage of soil moisture availability during the late season stage, hence, necessitating irrigation. Furthermore, wheat is also dominating crop in the district during the *rabi* season. From the analysis, it was found that the seasonal crop water requirement of wheat was 378 mm. Conversely, effective rainfall meets just a small portion of the overall crop evapotranspiration. Additionally, Maize and Chick Pea (Chana) crops are the other two main crops in the district during the *Kharif* and *Rabi* seasons, with seasonal crop water requirements of 286.4 mm and 270.9 mm, respectively. The analysis found that in the district, the proportion of effective rainfall used by soybean, wheat, maize, and mustard crops to fulfil crop evapotranspiration requirements was 63, 11, 88, and 13 per cent, respectively. According to the effective rainfall used by different crops, the maize crop was superior in utilizing ER. In contrast, the wheat crop exhibited the lowest percentage of effective rainfall usage. Although *kharif* crops consume a higher proportion of ER due to the onset of monsoon season matching the *kharif* crop's sowing/transplanting dates than *rabi* season crops, still, there was substantial heterogeneity among *kharif* crops in utilizing effective rainfall because of crop characteristics, growth duration, and sowing dates. Daily crop evapotranspiration rose from 1.51 mm/day (during the starting stage) to a maximum ET of 4.75 mm/day (during the mid-season stage) for the soybean crop. The seasonal average crop evapotranspiration rate was 3.18, 2.90, 3.20, and 2.39 mm/day for soybean, wheat, maize, and chick, respectively.

Crop evapotranspiration of major crops in the Guna district

In Guna district, soybean and wheat are the dominate crops during the *Kharif* and *Rabi* seasons. Additionally, other crops like maize, chickpeas, and mustard are cultivated. Table 10 presents data on ET_c, ER, and IR for the primary crops in Guna district. The estimation indicates that seasonal crop evapotranspiration for soybean, wheat, maize, chickpea, and mustard stood at 303 mm, 372.1 mm, 275.2 mm, 217.7 mm, and 289.7 mm, respectively. Notably, effective rainfall

Table 6: Decadal crop water requirement, effective rainfall, and irrigation requirement of Soybean in the Bhopal district

Month	Decade	Stage	Kc	ET_c	ET_c	Eff rain	Irr. Req.
			Coefficient	mm/day	mm/dec	mm/dec	mm/dec
Jul	2	Init	0.4	1.51	9.1	33.8	0
Jul	3	Init	0.4	1.48	16.3	55.4	0
Aug	1	Dev	0.48	1.76	17.6	53.9	0
Aug	2	Dev	0.76	2.63	26.3	54.4	0
Aug	3	Mid	1.04	3.81	41.9	52.1	0
Sep	1	Mid	1.11	4.32	43.2	52.6	0
Sep	2	Mid	1.11	4.49	44.9	52.1	0
Sep	3	Mid	1.11	4.58	45.8	37.8	8
Oct	1	Mid	1.11	4.75	47.5	18.9	28.6
Oct	2	Late	1	4.39	43.9	4.6	39.2
Oct	3	Late	0.67	2.69	29.6	4.2	25.4
Nov	1	Late	0.48	1.73	1.7	0.5	1.7
Total					**367.8**	**420.4**	**103**

Init- Initial stage, Mid-Middle stage, Dev-Development stage, late –Late stage

Table 7: Decadal crop water requirement, effective rainfall and irrigation requirement of Wheat in the Bhopal district

Month	Decade	Stage	Kc	ET_c	ET_c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.7	2.51	25.1	4.7	20.4
Nov	2	Init	0.7	2.26	22.6	2.4	20.1
Nov	3	Dev	0.72	2.19	21.9	2.8	19.1
Dec	1	Dev	0.83	2.39	23.9	3.4	20.5
Dec	2	Dev	0.96	2.58	25.8	3.5	22.3
Dec	3	Mid	1.1	3.05	33.6	4	29.6
Jan	1	Mid	1.15	3.31	33.1	4.9	28.3
Jan	2	Mid	1.15	3.43	34.3	5.5	28.8
Jan	3	Mid	1.15	3.76	41.4	4.1	37.2
Feb	1	Late	1.14	4.05	40.5	2	38.5
Feb	2	Late	0.92	3.55	35.5	0.6	34.9
Feb	3	Late	0.65	2.79	22.3	1.4	20.9
Mar	1	Late	0.38	1.81	18.1	2.7	15.4
Total					**378**	**42.2**	**335.9**

Table 8:Decadal crop water requirement, effective rainfall and irrigation requirement of Maize in the Bhopal district

Month	Decade	Stage	Kc	ET_c	ET_c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	2	Init	0.45	1.7	10.2	33.8	0
Jul	3	Init	0.45	1.67	18.4	55.4	0
Aug	1	Dev	0.52	1.89	18.9	53.9	0
Aug	2	Dev	0.74	2.58	25.8	54.4	0
Aug	3	Mid	0.97	3.57	39.3	52.1	0
Sep	1	Mid	1.03	4.02	40.2	52.6	0
Sep	2	Mid	1.03	4.18	41.8	52.1	0
Sep	3	Late	1.03	4.24	42.4	37.8	4.6
Oct	1	Late	0.97	4.14	41.4	18.9	22.4
Oct	2	Late	0.92	4.05	8.1	0.9	8.1
Total					**286.4**	**412**	**35.2**

sufficiently met the entire crop evapotranspiration demand for *Kharif* crops, specifically soybean and maize, rendering irrigation is minimal for these crops. However, during the *Rabi* season, effective rainfall contributed only 12.2%, 22.1%, and 18.0% of the crop evapotranspiration demand for wheat, chickpea, and mustard, respectively. This suggests that without irrigation, these crops could experience abiotic stress, potentially reducing their yields. Interestingly, mustard exhibited a relatively higher reliance on effective rainfall to meet a substantial portion of its ET_c requirements. From the

Table 9: Decadal crop water requirement, effective rainfall and irrigation requirement of Chickpea in the Bhopal district

Month	Decade	Stage	Kc	ET_c	ET_c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.4	1.29	7.7	1.5	6.5
Nov	3	Dev	0.4	1.22	12.2	2.8	9.4
Dec	1	Dev	0.51	1.46	14.6	3.4	11.2
Dec	2	Dev	0.68	1.83	18.3	3.5	14.8
Dec	3	Dev	0.86	2.4	26.4	4	22.4
Jan	1	Mid	0.99	2.87	28.7	4.9	23.8
Jan	2	Mid	1	2.98	29.8	5.5	24.3
Jan	3	Mid	1	3.27	36	4.1	31.8
Feb	1	Mid	1	3.55	35.5	2	33.5
Feb	2	Late	0.88	3.39	33.9	0.6	33.3
Feb	3	Late	0.59	2.53	20.3	1.4	18.9
Mar	1	Late	0.4	1.87	7.5	1.1	6.1
Total					**270.9**	**34.9**	**236**

Table 10: Seasonal crop evapotranspiration (ET_c), effective rainfall (ER), and irrigation requirements (IR) of crops in Guna Districts

Crop	ET_c, mm	ER, mm	IR, mm
Soybean	303	303	0
Wheat	372.1	45.4	326.9
Maize	275.2	275.2	0
Chickpea	217.7	47.4	169.9
Mustard	289.7	52.2	237.5

observation it was found that on average, the daily ET_c rates were 3.1 mm/day for soybean, 2.8 mm/day for wheat, 3.1 mm/day for maize, 1.9 mm/day for chickpea, and 2.2 mm/day for mustard crops. The daily average crop evapotranspiration can be valuable for planning irrigation scheduling in such regions and the design of irrigation systems. The variation in crop water requirements among the crops can be attributed to the diverse characteristics of these crops, including their growth cycles, root depths, and transpiration rates. Furthermore, it was found that the mustard crop has the potential to be a water-efficient crop in the region.

Crop evapotranspiration of major crops in the Indore district

The ET_c, ER, and IR of the major crops grown in the Indore district are shown in Table 11. As per the table, soybean, wheat, and chickpea exhibited seasonal crop evapotranspiration rates of 380 mm, 440.7 mm, and 311.1 mm, respectively. Notably, a significant portion of the soybean crop's (major *Kharif* crop) evapotranspiration requirement, approximately 85 percent, was satisfied by effective rainfall, while the remaining 15 percent necessitated irrigation. Effective rainfall contributed 12 percent and 12.3 percent to the total seasonal crop water requirement for *Rabi* season crops, specifically wheat and chickpea, respectively. It was found that there is slight difference in chick pean and wheat ER usage however, due to less of CWR for chickpea than wheat from this reason underscore the superior performance of the chickpea crop in efficiently utilizing effective rainfall during the *Rabi* season. The daily crop evapotranspiration needs to be estimated to estimate the seasonal crop water requirement and irrigation design. It was found that soybean, wheat, and chickpea were 380, 440.7, and 311.1 mm, respectively.

Crop evapotranspiration of major crops in the Khandwa district

According to Table 12, the seasonal crop evapotranspiration for soybean, wheat, sorghum, cotton, and chickpea amounts to 320.4 mm, 510.6 mm, 392.9 mm, 610.4 mm, and 311.1 mm, respectively. Effective rainfall significantly contributed to soybean water requirement, accounting for approximately 98.4%, whereas for wheat, sorghum, cotton, and chickpea, this contribution accounts at 6%, 73.2%, 55.4%, and 5.9%, respectively. This study underscores the superior efficiency of soybean in utilizing effective rainfall compared to other *Kharif* season crops. This

Table 11: Seasonal crop evapotranspiration (ET_c), effective rainfall (ER), and irrigation requirements (IR) of crops in Indore district

Crop	ET_c, mm	ER, mm	IR, mm
Soybean	380	323.9	56.1
Wheat	440.7	53	388.8
Chickpea	311.1	38.3	272.7

Table 12: Seasonal crop evapotranspiration (ET_c), effective rainfall (ER), and irrigation requirements (IR) of cropsin Khandwa district

Crop	ET_c, mm	ER, mm	IR, mm
Soybean	320.4	315.3	5.1
Wheat	510.6	30.1	388.8
Sorghum	392.9	287.5	105.4
Cotton	610.4	333	277.4
Chickpea	311.1	38.3	272.7

discrepancy highlights the exceptional ability of soybean to harness and utilize available rainfall efficiently. It also suggests that soybean is well-suited to the region's climate conditions, making it a viable and sustainable crop option, particularly during the *Kharif* season. The average daily crop evapotranspiration rates for soybean, wheat, sorghum, cotton, and chickpea were 3.3 mm/day, 3.8 mm/day, 3.1 mm/day, 3.5 mm/day, and 2.8 mm/day, respectively, providing valuable insights for design of irrigation system and management in the study region.

Crop evapotranspiration of major crops in the Neemuch district

In the Neemuch district, soybean, wheat, maize, mustard, and chickpea crops showed average crop evapotranspiration rates of 2.3, 2.8, 3.2, 2.3, and 2.2 mm/day, respectively. The seasonal crop evapotranspiration values for soybean, wheat, maize, mustard, and chickpea were determined to be 362.5 mm, 370.8 mm, 284.1 mm, 309.8 mm, and 252.1 mm, respectively, as presented in Table 13. The effective rainfall contribution to the soybean crop water requirement was approximately 86.1 per cent, with the remainder met by irrigation. In contrast, the effective rainfall contribution to the season crop water requirements of wheat, maize, mustard, and chickpea, respectively, was 19.9, 100, 11.4, and 8.8 per cent. This result shows that the maize crop was superior to the soybean crop in *kharif* season crops in terms of effective use of rainfall.

Crop evapotranspiration of major crops in the Sagar district

Table 14 contains effective rainfall, irrigation requirement, and crop evapotranspiration in the Sagar district. The Table found that soybean, wheat, black gram, lentil, and chickpea had seasonal crop evapotranspiration of 365.8, 415.2, 270.8, 309.1, and 284.5 mm, respectively.

Table 13: Seasonal crop evapotranspiration (ET_c), effective rainfall (ER), and irrigation requirements (IR) of crops in Neemuch

Crop	ET_c, mm	ER, mm	IR, mm
Soybean	362.5	312.3	50.2
Wheat	370.8	19.9	350.9
Maize	284.1	284.1	0
Mustard	309.8	35.4	274.4
Chickpea	252.1	22.4	229.7

Table 14: Seasonal crop evapotranspiration (ET_c), effective rainfall (ER), and irrigation requirements (IR) of crops in Sagar District

Crop	ET_c, mm	ER, mm	IR, mm
Soybean	365.8	321.3	44.5
Wheat	415.2	72.1	343.1
Blackgram	270.8	270.8	0
Lentil	309.1	66.7	272.4
Chickpea	284.5	62.9	221.6

The effective rainfall contribution to the soybean crop water demand was around 87.8%, while the effective rainfall contribution to the season crop water requirements of wheat, maize, mustard, and chickpea, respectively, was 17.3, 100, 21.5, and 22.1 per cent. Wheat has the highest irrigation demand, followed by lentils and chickpeas. In terms of effective usage of the rainfall, this data reveals that maize was superior to soybean in *kharif* season crops. The average crop evapotranspiration rate in the Sagar district for soybean, wheat, black gram, lentil, and chickpea crops was 3.3, 3.2, 3.0, 2.6 and 2.5 mm/day.

District-specific analysis of maximum crop evapotranspiration rates

The determination of peak consumptive usage rates for crops in the selected regions is a pivotal aspect in the quest for efficient irrigation system design. This analysis revealed notable variations in the maximum crop evapotranspiration rates across the districts under the prevailing *Kharif* and *Rabi* cropping pattern. Specifically, Khandwa district exhibited the highest rate at 6.24 mm/day, followed by Indore, Bhopal, Sagar, and Guna, while Neemuch district registered the lowest rate at 4.59 mm/day. These findings, as illustrated in Figure 6, hold significant implications for the development of water management strategies and infrastructure. The observed differences in peak consumptive usage rates underscore the need for tailored approaches to irrigation system design and crop management in each district. In regions with higher evapotranspiration rates, such as Khandwa, there is a heightened demand for water resources during the crop growing seasons. This necessitates the development of robust water storage structures and advanced irrigation systems capable of meeting these demands efficiently. Conversely, districts with lower peak consumptive usage rates, like Neemuch, may require less intensive irrigation infrastructure. However, it is crucial to strike a balance between conserving water resources and ensuring that crops receive adequate moisture during critical growth stages. This involves the strategic design and management of irrigation systems that consider factors such as soil characteristics, crop varieties, and local climate conditions. Moreover, these findings provide a valuable foundation for the formulation of region-specific crop management strategies. Farmers and policymakers can use this data to optimize crop planting schedules, irrigation timing, and water allocation practices. Ultimately, the goal is to maximize agricultural productivity while minimizing water wastage and promoting sustainable resource management.

Water stress management strategies

Given the rising water scarcity, agriculture is of critical importance to the global food supply (Sun *et al..,* 2012; Li *et al.*., 2017). Global warming and erratic rainfall patterns, on the other hand, are too responsible for the scarcity of water resources, which limits agricultural productivity in arid and semi-arid regions (Qin *et al.*., 2015; Li *et al..,* 2017). As a result, conservative and effective water usage has been practised successfully and needs to be implemented. These water management strategies (Figure 7.) are detailed in the following sections.

Water harvesting for supplemental irrigation

The potential of supplemental irrigation through rainwater harvesting as a means to enhance agricultural productivity and improve livelihoods in arid and semi arid rainfed regions. The concentration of rainfall during a specific period, from mid-June to mid-September, often leads to issues like runoff, waterlogging, sedimentation and soil erosion. To harness this precious resource, rainwater harvesting structures must be employed for effective storage and utilization of rainfall in crop cultivation. This practice aligns with the findings of Oweis and Hachum (2006), highlighting the significance of supplemental irrigation in optimizing crop yields in such environments. Interestingly, despite the importance of rainwater harvesting, there has been a relative scarcity of studies focusing on its effectiveness for deficient supplemental irrigation, especially in the context of macro-catchment rainwater harvesting systems (Assefa *et al..,* 2016). Nevertheless, numerous experimental studies conducted in rainfed agricultural settings have consistently demonstrated that rainwater collection structures can alleviate water constraints throughout the entire crop growth cycle (Jo and Garry, 2003; Singandhape *et al..,* 2003; Xu and Mermoud, 2003; Khan *et al..,* 2021; Patrick *et al..,* 2004). These

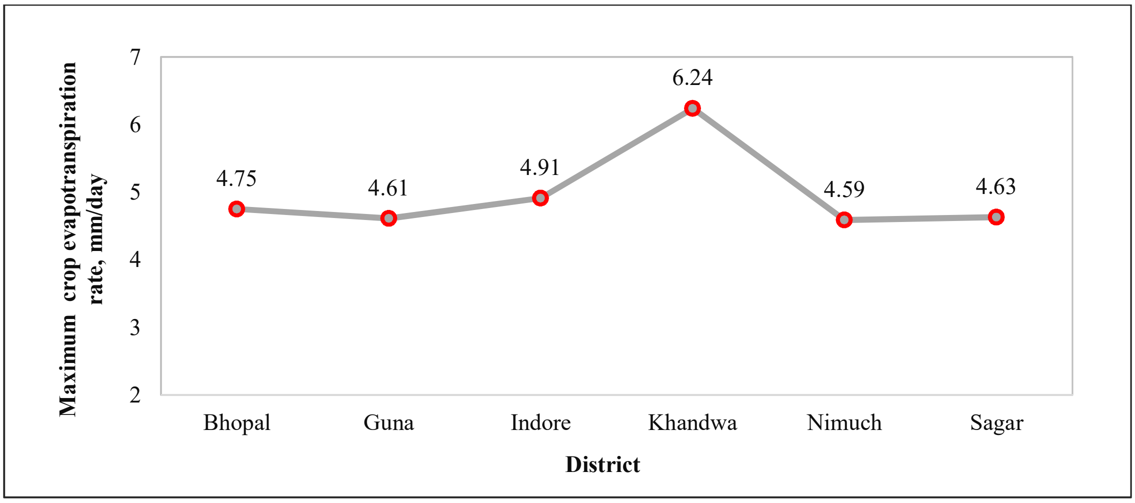

Figure 6: Maximum crop evapotranspiration rate for various districts

Figure 7. Water stress management strategies under water scarce conditions

findings underscore the viability of rainwater harvesting as a sustainable solution to enhance agricultural water availability. Despite the benefits of rainwater harvesting, it's important to acknowledge the inevitability of drought conditions during specific crop developmental stages (Kang *et al..,* 2002; Pan *et al..,* 2003). In response to such challenges, the utilization of water collected in small ponds for additional irrigation, as suggested by Xiao *et al..,* (2005), emerges as a viable option in such circumstances. This demonstrates the need for a multifaceted approach to water management, ncombining rainwater harvesting with other irrigation strategies to address varying water availability throughout the crop's growth cycle. In our study it was suggested that such interventions is required to harvest the excess rainfall and store and use it for critical irrigation in rabi season in order to avoid crop stress, eventually to get optimal yield.

Altering sowing/transplanting dates

Modifying the timing of planting or transplanting can have favourable impact on optimizing the efficient utilization of rainfall resources, leading to a reduction in the demand for irrigation or supplemental irrigation without compromising crop productivity. Research in the context of wheat cultivation, as exemplified by the study conducted by Bana *et al..,* (2022), demonstrates that sowing wheat during the initial fortnight of November can result in a notable reduction, approximately 20-25%, in blue water requirements compared to sowing it toward the end of December. Beyond a certain planting date, a dual challenge emerges, characterized by a decrease in crop yield (approximately 20-22%) and an increased demand for irrigation water. Similarly, observations from a study on paddy transplanting in Punjab, as conducted by Mahajan *et al.*., (2009), indicate that delaying the transplanting date from June 15th to July 5th led to yield reductions ranging from 7% to 16%. Aligning crop sowing and transplanting schedules with the onset of the monsoon season could potentially Mitigating crop stress, along with optimizing the utilization of effective rainfall, results in a diminished need for irrigation. Rajput *et al.*., 2022 estimated crop water requirement of the rice, wheat, sugarcane and sunflower for Kurukshetra district, Haryana. They reported that the date of sowing/transplanting has a great influence on crop water requirements and thus water demand. Therefore, it is highly desirable to match the optimum date of sowing/transplanting for lesser crop water demand and thus efficient management of the water demand.

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Soil moisture conservation techniques

Enhanced agronomic techniques, including intercropping, mulching, contour farming, crop residue management, and mechanical procedures like laser land leveling, offer valuable for Soil moisture conservation technique. These practices yield several benefits such as the even distribution of irrigation water, reduced usage of fertilizers and chemicals, expanded coverage for irrigation due to enhanced application and distribution efficiency, conservation of soil and water resources, and enhanced crop development and yield (Whitney *et al..,* 1950; Brye *et al..,* 2005). The adoption of zero-tillage methods has been observed to result in significant water savings, ranging from 20% to 35% reduction in irrigation water usage (Nagarajan *et al..,* 2002). As a consequence, issues related to waterlogging and wheat crop yellowing following initial irrigation are minimized (RWC, 2004). Furthermore, zero-tillage practices decrease the necessity for single irrigation events (Laxmi *et al..,* 2003; Malik *et al..,* 2002; Mehla *et al..,* 2000). When wheat crops are cultivated on raised beds, a substantial reduction in irrigation water consumption of approximately 30-40% is achieved in comparison to conventionally seeded crops. Additionally, this approach leads to increased yields and reduced concerns related to pests and diseases (Jat *et al..,* 2005).

Micro irrigation systems

Adopting a micro irrigation system will enhance the irrigation conveyance efficiency and reduce the losses compared to surface irrigation. A study was conducted by (Meena *et al..,* 2015) to improve water use efficiency (WUE) in rice-wheat cropping systems through a micro-irrigation system. The WUE of the check basin approach was the lowest (1.32 kg/m^3). Conversely, drip combined with rain port irrigation (5545 kg/ha) yielded the maximum yield, followed by drip irrigation (5475 kg/ha) with WUEs of 1.57 and 1.55 kg/m^3. In rice, drip irrigation produced significantly better grain yields (4028 and 4683 kg/ha) than sprinkler irrigation. The study found that the highest WUE in wheat was achieved using a drip and rainport treatment, whereas the highest WUE in rice was achieved using drip irrigation. Another study was conducted using drip and sprinkler irrigation systems installed in the onion field; it was found that 37.8 and 32.5 % of water saving was done in drip and sprinkler irrigation, respectively. Furthermore, a significant increase in the yield was also observed (Lawande, 2008). According to the findings of such adoption strategies are essential in the study region in both season where that area is under water scares condition, such interventions will help us improve WUE and crop yield by minimizing water-related stress and maintaining optimal soil moisture at the root level.

Adoption of drought tolerance varieties

The adoption of drought-tolerance cultivars, especially within the realm of agriculture, carries substantial consequences for enhancing productivity, mitigating risks, and improving overall well-being. Dasgupta *et al.*., (2015) conducted a study examining the impact of water stress on drought resistance in rice cultivation. Their findings unveiled that the utilization of drought-tolerant rice cultivars led to a notable increase in crop yield, ranging from 8% to 44%. Furthermore, this induced water stress resulting from a limited water supply presented an opportunity to devise an efficient water-saving approach for lowland rice farming. Additional irrigation techniques capable of inducing water-related stress include deficit irrigation (DI) and partial root drying (PRD). DI involves maintaining minimal water usage, with the resulting minor stress exerting limited influence on crop yield. Conversely, PRD entails watering only half of the root system while allowing the other half to become desiccated. In comparison to full irrigation, the application of PRD conserved approximately 30% of water resources and significantly enhanced crop water use efficiency (WUE) by nearly 60%, all without incurring any significant loss in tuber yield (Jensen *et al..,* 2010). In the rabi season, it is imperative to consider implementing these measures for enhancing crop water productivity, particularly for maize and jowar cultivation in regions where water resources are limited. Various studies have indicated that the adoption of certain stress-inducing techniques may not only improve crop quality but also enhance oil content and aroma in specific crops. However, it is essential to apply these methods in a scientifically validated manner. In a study conducted by Surendran *et al..* (2015) in the Palakkad district of Kerala, the CROPWAT 8.0 model was utilized to assess future water demands for irrigation, drinking, and industrial purposes. The findings revealed that the projected total water demands for these purposes were estimated to be 3841 Mm^3. However, the available water resources were insufficient to meet this demand. As a result, the study suggests that under such conditions, deficit irrigation strategies could be adopted to optimize water use for irrigation while still aiming for higher crop yields. Such type of deficit irrigation may be adopted in the water scare regions of MP for crop production in both seasons. Such type of intervention may improve the quality and quantity of irrigation. Again, this type of approach needs to be scientifically tested for each district and then standard operating procedure need to be established before adopting deficit irrigation in MP district. Chakravrti *et al..* (2022) revealed that the month of February necessitated the most substantial water supply. Consequently, the utilization of drought-tolerant crops and the implementation of deficit irrigation methodologies offer viable alternatives in water-stressed or arid regions characterized by acute water scarcity. These approaches hold promise for augmenting crop yields while simultaneously conserving water resources. The research identifies the maximum consumptive usage rate for crops in each selected area, with the most elevated rate observed in the Khandwa district and the lowest in the Neemuch district. These findings hold valuable implications for the design of efficient irrigation systems, planning of water storage structures, and formulation of crop management strategies. In a study conducted by Gangwar *et al..,* (2017) within the Bina command area of Sagar district, wheat, gram-pulses, and mustard were found to exhibit crop water requirements of 349.8 mm, 304.1 mm, and 316.9 mm, respectively. These results suggest that farmers in these districts can capitalize on effective rainfall to fulfil a substantial portion of the water needs for maize cultivation, thus diminishing the necessity for irrigation. In the research conducted by Chakravrti *et al..* (2022) in MP district, an investigation was undertaken to evaluate the water requirements of various crops. Their findings indicated that wheat exhibited the highest demand for water, whereas maize demonstrated the lowest water requirement consistently across different time periods. Likewise, Rajput *et al..*, 2022 estimated crop water requirements of principal crops *Kharif* and *Rabi* season crops Bhimsagar Canal Command area in Jhalawar, Rajasthan. The crop water requirements of wheat, mustard, coriander, and garlic were found to be 345.2 mm, 323.9 mm, 273.7 mm and 515.1 mm, respectively. They also found that the crop water requirements were varied in different years mainly due to variation in the weather parameters. The crop water requirement is influenced by the crop characteristics, soil properties, and climatic factors. In our current study we found varying crop water requirement for different in different districts which is mainly due to variation in the climatic condition prevailing. Therefore, it is desirable to estimate crop water requirements precisely for a given location for better irrigation planning. In a similar study conducted by Kumar Shaw *et al..,* (2019) in Kurnool district, which experiences hot and arid climatic conditions, it was observed that maize had a NIR

(Net Irrigation Requirement) value of 220 mm. The findings revealed that maize had the highest dry yield, with a significant yield of 13.586 tonnes per hectare, indicating that maize may be the potential best-performing crop where the similar climatic condition observed in the MP districts similarly

Yadav *et al..*, (2018) conducted a study on water needs for crops in *rabi* and *kharif* seasons across twenty diverse districts of MP. They found that Jabalpur had the highest daily water requirements for chickpea (1.73 lpd), wheat (0.70 lpd), and lentil (0.49 lpd) during the *rabi* season. The results presented in the report differ from our own findings, and this disparity could be attributed to variations in factors such as altered sowing dates, distinctive crop attributes, soil conditions, and local climatic parameters within the study area. In Narsinghpur, sugarcane had the highest water requirement during the mid-season, at 13.56 lpd. In the *kharif* season, Harda stood out with cotton requiring 6.53 lpd, while sesame and groundnut needed 2.75 lpd and 2.46 lpd in Datia. Furthermore, Singh *et al..*, (2013) findings revealed that the CWR for soybean amounted to 401.6 mm, while for wheat, it was calculated to be 352.2 mm. Specifically, during the *kharif* season, soybean cultivation necessitated at least one irrigation event (especially in the event of an early monsoon withdrawal) to meet the crop's water requirements, primarily in September during the critical pod development stage. For the *rabi* season, wheat cultivation required irrigation from November to March, underscoring the imperative of rainwater runoff storage within the region to ensure a sustainable water supply for agricultural practices. Both studies are highlighting the irrigation management strategies more essential in the *rabi* season. Similar findings are also reported from our study.Thimmareddy *et al..,* (2022) conducted a study on chick pea using CROPWAT to assess the water requirement under climate changing condition and found that yield under rainfed condition and average number of irrigations reduced by 18.5 % and 42.9 %, respectively, under such condition suitable crop management practice is necessary for enhancing yield. In a similar study conducted by Gabr *et al..*, (2019) in Tina Plain and East South ElKantara regions of North Sinai, Egypt, the net irrigation requirements of different crops were examined using FAO-CROPWAT 8.0 and CLIMWAT 2.0 models. The results revealed variations in net irrigation requirements across crops and regions. In Tina Plain (AER 1), berseem clover, barley, and cotton had net irrigation requirements of 612 mm, 283 mm, and 901 mm, respectively. In East South ElKantara (AER 2), the corresponding values were 738 mm, 287 mm, and 1113 mm, indicating a 19% increase compared to AER 1. Thomas *et al..*, (2014) suggested irrigation strategies to support sustainable rain-fed agriculture in a drought-vulnerable environment. Their analysis of dry spell patterns during crop growing season highlighted the necessity of implementing supplementary irrigation practices to ensure the viability of agricultural operations. The study further involved the estimation of supplemental irrigation needs during critical dry spell periods for every development block across all districts. These findings underscore the importance of implementing better water management practices, focusing on improving irrigation efficiency, and cultivating crops with lower water requirements, such as green beans, wheat, barley, sugar beet, and tomato. In light of the comprehensive examination of research and discoveries, it becomes evident that embracing sustainable irrigation and rainwater harvesting is imperative to bolster agricultural resilience in the face of climate change, effectively addressing its adverse effects on both agriculture and water resources.

Conclusion

In conclusion, this study aimed to assess crop water requirements and irrigation needs in six districts across diverse agro-climatic regions in Madhya Pradesh, employing CLIMWAT 2.0 and CROPWAT 8.0 software. These tools were instrumental in estimating crop evapotranspiration, formulating irrigation schedules, and customizing irrigation strategies based on local climatic conditions. Our findings revealed the prevalence of the soybean-wheat cropping pattern across all districts, alongside notable variations in crop water requirements attributable to differences in climatic parameters, soil characteristics, and crop varieties. Particularly, the Khandwa district exhibited the highest seasonal evapotranspiration for cotton, attributed to its extended growing season (150 to 180 days) and unique climatic attributes. Conversely, the Indore district demonstrated the highest crop water requirement for soybean, while the Guna district exhibited the lowest. In a similar vein, for wheat, Khandwa registered the highest seasonal crop evapotranspiration, while Neemuch reported the lowest value. In addition, this study underscored the reliance of specific crops, such as maize and soybean, on effective rainfall during the *Kharif* season, while others, including wheat, chickpea, and mustard, leaned more heavily on irrigation due to inadequate rainfall during the *Rabi* season. Which was displayed the highest irrigation water requirement during the *Rabi* season. These findings emphasize the critical need for tailored water management strategies to enhance crop water use efficiency and reduce dependence on irrigation, especially in drought-prone regions. The significance of district-specific considerations, encompassing climate and soil attributes, is evident. Promoting practices such as crop diversification, efficient irrigation, and rainwater harvesting, alongside supporting research, financial incentives, and monitoring, will further advance sustainable water management in water-scarce regions.

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Conflict of interest
The authors declare that they have no conflicts of interest.

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