Multiobjective Nonlinear Model Predictive Control of Forestry Problems

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Abstract: The use of rigorous computational tools is necessary to control forest pollution and minimize carbon dioxide emissions. In this work, a rigorous multi objective nonlinear model predictive control strategy is adopted on three different forestry models. The optimization was performed with the optimization language PYOMO in conjunction with the state-of-the-art optimization solvers IPOPT. The globality of the solutions was confirmed with the global optimization solver BARON. The optimum profiles generated show that this strategy is effective in minimizing the carbon dioxide emissions, and forest pollutants maximizing the forest biomass density. The control of non-wood-based industrial activity is beneficial to keep the depletion of forestry as low as possible and minimize the emission of unwanted carbon dioxide into the atmosphere.

Keywords: Multiobjective, Optimization, Industries, Forest

The presence of forests and forested areas is very beneficial for the health and well-being of humanity. The rise of industrial and residential areas arising from population growth has led to deforestation and the destruction of a lot of greenery. This coupled with industrialization has led to the production of a lot of carbon dioxide which is detrimental to human health. A lot of computational work has been performed studying the dynamics of various situations involving forestry, specifically optimal control. However, all the work so far involves single-objective optimal control. Computational techniques have been used by several researchers to model forest depletion caused by population increase and industrial development. Shukla and co-workers (1989, 1996, 2003, 2006, 2009) performed computational work on effects of population growth, industrialization and pollutant formation on forest density. Freedmanand Shukla (1991) developed models for the effect of toxicant in single-species and predator-prey systems.Shukla and co-workers (2003) studied the effects of primary and secondarytoxicants on renewableresources. Similarly, Naresh et al (2006) computationally investigated the effect of an Intermediate toxic product formed by uptake of a toxicant on plant biomass. Shukla et al (2009) modelled the survival of a resource dependent population, studying the effects of toxicants (pollutants) emitted fromexternal sources as well as formed by its precursors. Dubey and Narayanan (2010) worked out the interactions between industrialization, population and pollution. Shah et al (2017) performed optimal control studies for the spread of pollutants through forest resources. Irma Fitria et al (2021) modeled the dynamics of CO_2 emission, forest area, and industrialization and used optimal control to minimize the carbon dioxide emission. Betancourt et al (2024) observed the changes in timber yield of commercial tree species in the eastern Brazilian Amazon based on 33 years of inventory data. This paper deals with the performance of multiobjective nonlinear model predictive control (MNLMPC) tasks on the three models described by Dubey et al (2009) and Shah et al (20170 and Irma Fitria et al (2021). First, the three problems involving forestry are described. This is followed by a discussion of the MNLMPC strategy. Then the MNLMPC results for each of the three problems are presented along with a detailed discussion. This is followed by a summary of the results and the conclusions.

MATERIAL AND METHODS

Problem 1: In this problem (Irma Frita el al 2021) the variables are:

- X the carbon dioxide concentration,
- I the industrial existence,
- Z, the forest presence.

The parameter values are

- r, the growth rate of carbon dioxide concentration, =0.15((1/year),
- s, the carrying capacity of carbon dioxide=700(ppm),
- α, the emission reduction due to forest resources, =0.06 (ppm ha^{-1} yeat^{-1})

- h_1, the emission growth rate due to industrialization=0.8 (ppm/year),
- h_2, the natural depletion rate of forest resources=1(1/year),
- β (industrialization growth rate) =0.1(ha^{-1}),
- h_3 (depletion rate of forest resources) =0.02(1/year),
- γ, the natural forest growth rate =0.07 (1/year).

The control variables are u_1 (the optimal control of the reforestation) and u_2 (the optimal control of government policy). The equations are (1-3)

$$\frac{dX}{dt} = rX(1-\frac{X}{s}) - \alpha Z + h_1 I \qquad (1)$$

$$\frac{dZ}{dt} = (\gamma + u_1 - h_1 - h_3 I)Z \qquad (2)$$

$$\frac{dI}{dt} = (\beta h_3 Z - u_2)I \qquad (3)$$

Problem 2: In this problem (Dubey et al 2009) the variables are

- B (t) is the density of resources biomass density,)1/ha)
- N(t) is the cumulative density of populations, (1/ha)
- P(t) is the population density pressure, (1/ha)
- I(t) the industrialization density. (1/ha)

The parameters are

- s is the intrinsic growth rate = 34 (1/year)
- L is the carrying capacity = 40 (1/ha)
- S_0 is the resource biomass natural depletion rate coefficient=1
- r_0 is the population natural depletion rate coefficient=10
- β_1 the population cumulative density growth rate because of resources 0.01 (1/ha)
- β_2 the depletion rate coefficient of the resource biomass density due to population=7 (1/year)
- λ, The population pressure growth rate coefficient =5 (1/year)
- λ_0, the natural depletion rate coefficient =4 (1/year)
- θ the depletion rate coefficient caused in augmenting industrialization =8,(1/year)
- S_1 is the depletionrate coefficient of the biomass density resulting from industrialization =4, (1/year)
- π_1, industrialization growth rate because of resource= 0.005 (1/ha)
- π is the industrialization growth rate because of population pressure= 0.001. (1/ha)

θ_0 is the control coefficient because of governmental regulations and is the control variable. The equations involved are (4-7)

$$\frac{dB}{dt} = s(1-\frac{B}{L})B - s_0 B - \beta_2 NB - s_1 IB \qquad (4)$$

$$\frac{dN}{dt} = r(1-\frac{N}{K})N - r_0 N + \beta_1 NB \qquad (5)$$

$$\frac{dP}{dt} = \lambda N - \lambda_0 P - \theta P \qquad (6)$$

$$\frac{dI}{dt} = \pi \theta P + \pi_1 s_1 IB - \theta_0 I \qquad (7)$$

Problem 3: In this (Shah et al , 2017) variable are

- W is the density of wood-based industries (1.ha)
- F is the density of forest resources(1.ha)
- I is the density of non wood based industries (1.ha)
- PI represents the pollutants through non-wood-based industries (ppm)
- PW is the pollutants through -wood-based industries (ppm) (8-12)

$$\frac{dF}{dt} = B - (\beta W + g)F - \beta_1 FW + \varepsilon_1 P_W - \gamma_1 F - \gamma_2 F + \varepsilon_2 P_I + u_1 W - \mu F \quad (8)$$

$$\frac{dW}{dt} = (\beta W + g)F + \beta_1 FW - \delta_1 W + \delta_2 I - \eta_1 W - u_1 W - u_2 W - \mu W \quad (9)$$

$$\frac{dI}{dt} = QI + \delta_1 W - \delta_2 I - \eta_2 I - u_3 I - \mu I \quad (10)$$

$$\frac{dP_W}{dt} = \eta_1 W - \varepsilon_1 P_W + \gamma_1 F + u_2 W - \mu_W P_W \quad (11)$$

$$\frac{dP_I}{dt} = \eta_2 I - \varepsilon_2 P_I + \gamma_2 F + u_3 I - \mu_I P_I \quad (12)$$

The parameter values are

- B the rate of compactness degree of forest resources=100 (1/year)
- Q The constant rate of resources provided to non-wood based industries (1/year)
- which does not depend on forest resources = 0.6 (1/year)
- g Migration of wood based industries to the forest region which directly depends on the density of forest resources =0.8 (1/year)
- β The depletion rate of forest resources due to wood based industries =0.04 (1/year)
- β_1 The growth rate of wood based industries due to forest resources =0.003 (1/year)
- μ The natural depletion rate =1 (1/year)
- μ_W The natural depletion rate of pollutants emitted from wood based industries=1 (1/year)
- μ_1 The natural depletion rate of pollutants emitted from non-wood based industries =1 (1/year)
- δ_1 he rate of competition effects of I on W =0.5 (1/year)
- δ_2 The rate of competition effects of W on I=0.3 (1/year)
- ε_1 The loss of pollutants generated by wood-based industries due to forest resources =0.02 ppm

• ε_2 The loss of pollutants generated by nonwood-based industries due to forest resources =0.01 ppm

• γ_1 The depletion rate of forest resources caused by the pollutants generated through wood-based industries =0.5 (1/year)

• γ_2 The depletion rate of forest resources caused by the pollutants generated through nonwood-based industries =0.5 (1/year)

• η_1 The growth rate of pollutants generated by wood-based industries =0.1 (1/year)

• η_2 The growth rate of pollutants generated by wood-based industries =0.7 (1/year)

The control variables in the problem are

• u1 is the rate that decreases wood-based industries to control the usage of forest resources.

• u2 is the control rate that decreases pollutants due to wood-based industries

• u3 is the control rate that decreases pollutants due to non-wood-based industries

MNLMPC (Multiobjective Nonlinear Model prediotive control) method: The multiobjective nonlinear model predictive control strategy (MNLMPC) method was first proposed by Flores Tlacuahuaz (2012) and used by Sridhar [2019]. This method does not involve the use of weighting functions, nor does it impose additional constraints on the problem unlike the weighted function or the epsilon correction method (Miettinen, 1999). For a problem that is posed as

$$\min J(x,u) = (x_1, x_2....x_k)$$
$$subject\ to\ \frac{dx}{dt} = F(x,u)$$
$$h(x,u) \leq 0 \qquad (13)$$
$$x^L \leq x \leq x^U$$
$$u^L \leq u \leq u^U$$

The MNLMPC method first solves dynamic optimization problems independently minimizing/maximizing each x_i individually. The minimization/maximization of x_i will lead to the values x_i^*. Then the optimization problem that will be solved is

$$\min \sqrt{\{x_i - x_i^*\}^2}$$
$$subject\ to\ \frac{dx}{dt} = F(x,u)$$
$$h(x,u) \leq 0 \qquad (14)$$
$$x^L \leq x \leq x^U$$
$$u^L \leq u \leq u^U$$

This will provide the control values for various times. The first obtained control value is implemented and the remaining

discarded. This procedure is repeated until the implemented and the first obtained control value are the same. In optimization package in Python, Pyomo differential equations are automatically converted to a Nonlinear Program (NLP) using the orthogonal collocation method (Biegler 2007) . The Lagrange-Radau quadrature with three collocation points is used and 10 finite elements are chosen to solve the optimal control problems. The resulting nonlinear optimization problem was solved using the solvers IPOPT(Wachter et al 2006) and confirmed with Baron (Tawarmalani 2005) To summarize the steps of the algorithm were:

1. Minimize/maximize x_i subject to the differential and algebraic equations that govern the process using Pyomo with IPOPT and Baron. This will lead to the value x_i^* at various time intervals t_i. The subscript i is the index for each time step.

2. Minimize subject to the differential and algebraic equations that govern the process using Pyomo with IPOPT and Baron. This will provide the control values for various times.

3. Implement the first obtained control values and discard the remaining.

Repeat steps 1 to 4 until there is an insignificant difference between the implemented and the first obtained value of the control variables.

RESULTS AND DISCUSSION

Problem 1: The multiobjective nonlinear model predictive control problem involves the maximization of the forest presence, and at the same time minimizing the industrial experience and carbon-dioxide emissions. This is equivalent to maximizing ΣZ_i while minimizing ΣX_i and ΣI_i. ΣZ_i The maximization of results in a value of 100, while the minimization of ΣX_i and ΣI_i results in values of 0 for each. The overall minimization objective function will be $(\Sigma I_i - 100)^2 + (\Sigma X_i - 0)^2 + (\Sigma I_i - 0)^2$ subject to the equations governing this problem. The MNLMPC strategy will ultimately reduce the emanation of carbon dioxide X, with the increase in forestation and the reduction of industrial density(Figs 1a-1e).

Problem 2: The density of resources biomass density, is maximized and the population density pressure is minimized. This is equivalent to maximizing ΣB_i and minimizing ΣP_i / The maximization of ΣB_i results in a value of 40.016, while the minimization of ΣP_i results in a value of 0. The multiobjective optimization results in the minimization of $(\Sigma B_i - 40.016)^2 + (\Sigma P_i - 0)^2$ subject to the equations governing this problem. This strategy results in the increase in biomass density and the reduction in industrial density (Fig. 2a-2c).

Problem 3: Here, P_w, P_i are both minimized while F, W and I
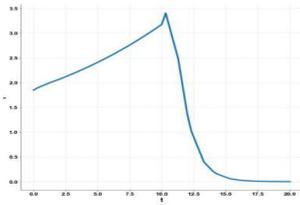
Fig. 1a. I vs t diagram for problem 1
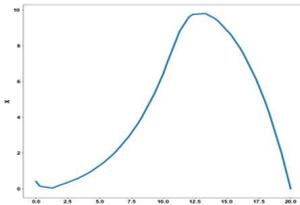
Fig. 1b. I vs t diagram for problem 1
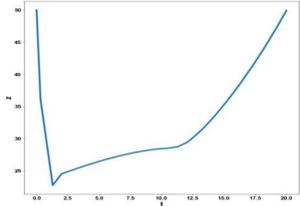
Fig. 1c. z vs t diagram for problem 1
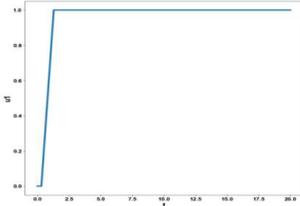
Fig. 1d. u1 vs t diagram for problem 1
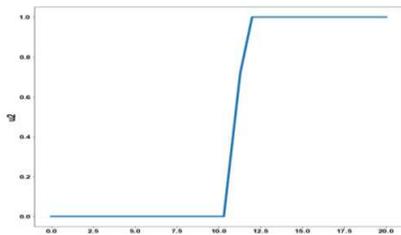
Fig. 1e. u2 vs t diagram for problem 1
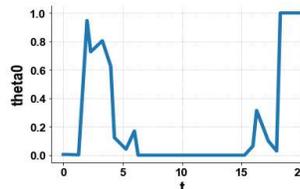
Fig. 2a. theta0 vs t for problem 2
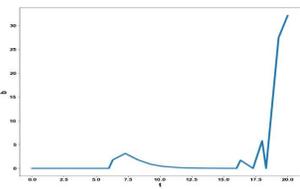
Fig. 2b. b vs t for problem 2
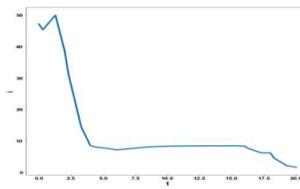
Fig. 2c. i vs t for problem 2
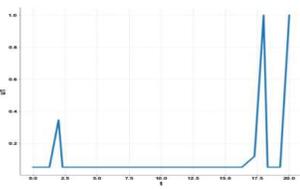
Fig. 3a. u1 vs t for problem 3
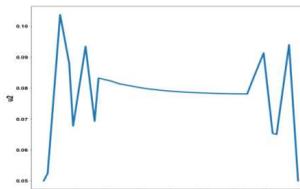
Fig. 3b. u2 vs t for problem 3

Fig. 3c. u3 vs t for problem 3
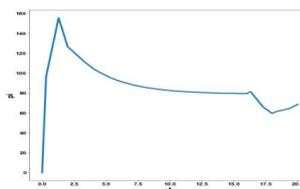
Fig. 3d. (pi vs t problem 3)
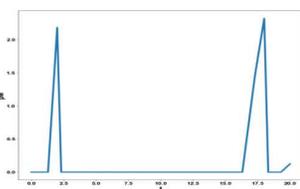
Fig. 3e. (pw vs t problem 3)
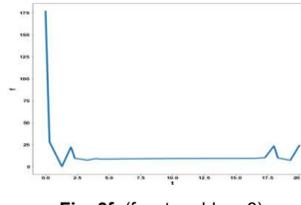
Fig. 3f. (f vs t problem 3)
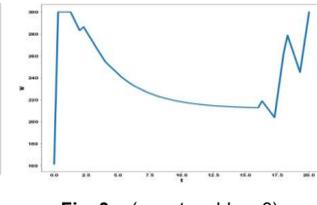
Fig. 3g. (w vs t problem 3)
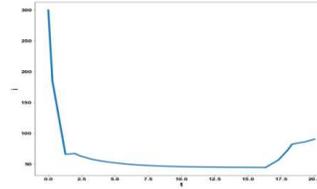
Fig. 3h. (i vs t problem 3)

are maximized. The minimization of H P_w, P_l lead to values of 0 and 58.73, while the maximization of F, W and I lead to values of 314.19, 600 and 411.71. The objective function for the multiobjective optimization will be

$$(P_w - 0)^2 + (P_l - 58.73)^2 + (F - 314.19)^2 + (W - 600)^2 + (I - 411.71)^2$$ subject to the equations representing this problem. The various profiles are shown in figures 3a-3h

Indicate the reduction of non-wood based industries causes a reduction in forest pollution.

In each of the three problems the variable I ultimately reduces with time using this strategy. The multiobjective nonlinear model predictive control strategy demonstrates that the minimization of the non-wood based industrial activity reduces carbon dioxide emissions, and other forest pollutions and increases biomass density in a given area.

CONCLUSIONS

A rigorous multiobjective optimal control procedure that does not involve additional constraints or weighting functions is used on forestry models. The main finding is that to increase biomass density, carbon dioxide emission and forest pollutants must be minimized . It is seen that controlling the non-wood industrial activity is essential to achieve these pbjectives.

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Wild Edible Plant Resources of the Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

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Abstract: The study was conducted in the Baspa Valley of district Kinnaur, Himachal Pradesh to know the diversity, distribution and conservation status of wild edible plants. A total of 95 wild edible plants belonging to 41 families and 76 genera were recorded, out of this 38 species were native to the Himalayan Region and 11 species were native to the Himalayan and other biogeographical regions together. Two species, i.e., *Bergenia stracheyi* and *Pinus gerardiana* were endemic and 20 species were near-endemic to the Himalayan region. The 15 species are in various threat categories of the IUCN redlist and Conservation Assessment and Management Prioritization 2003 and 2010 list. Leaves and fruits were utilized in the majority of cases. Thirty-nine species were most preferred and commonly utilized however 58 species were utilized occasionally as per need and availability. Currently consumption of wild edible plants and the knowledge associated is declining due to a number of reasons. Therefore, conservation of natural habitats, frequent monitoring of populations and habitat, domestication through the development of cultivation techniques, awareness programmes for the conservation of plants, traditional knowledge and development of value addition products needed for food, nutrition and economic security of the region.

Keywords: Baspa Valley, Conservation, Diversity, Kinnaur, Threat status, Wild edibles

Plants have been used by human beings as a source of food as well as medicine from time immemorial. The Indian Himalayan Region (IHR) is one of the world's richest biological diversity reserves. Due to wide variation in altitude, climate and ecological niche IHR supports approximately 47.06 % of flowering plants in India (Samant and Dhar 1997) of which 30% are endemic. This existing biodiversity is utilized by Himalayan communities for fulfilling daily household needs viz., food, fodder, fuel, timber, medicine, fiber, agricultural/household items and to perform various traditional rituals .Wild plants are the major source of food for rural and tribal communities residing in IHR and they often collect different parts of wild edible plants viz., roots, stems, leaves, flowers, fruits and seeds as per their seasonal availability. *Rhododendron arboreum, Bombax ceiba, Ficus palmata, Myrica esculenta, Zanthoxylum armatum, Ziziphus mauritiana, Diplazium esculentum, Indigofera heterantha, Bauhinia variegata*, *Morchella esculenta* and *Aegle marmelos* are some of the common examples of edible food plants of IHR (Lal et al 2018, Prasad and Sharma 2018 and Negi et al 2020). Due to limited income sources majority of people residing in IHR collects and consume wild edible plants as supplementary or substitute food and also market them as economic source (Prasad and Sharma 2018). Due to medicinal and curative properties, these plants are also used as protective foods (Sathyavathi and Janardhanan 2014) and in times of scarcity of fresh vegetables especially in

winter the dried or preserved forms of these plants also act as an important source of supplementary food for tribal communities(Samant et al 2001). Instead of huge potential in local, national and international market, the use of these wild edible plants is limited to certain areas/communities. There is vast scope for enhancing the wide acceptability of wild edibles as an income generating source for the people of IHR and a potential plant resource for human consumption (Sen et al 2013). History also reveals that wild edible plants have helped people survive wars and natural disasters (Redzic et al 2010, Turner et al 2011). Although the usage of wild edible plants is diminishing very fast throughout the world there are many parts of the world too, where the communities are still using them for fulfilling their dietary needs (Ali-Shtayeh et al 2008) especially in those regions where vegetable cultivation is done in the small scale and market supplies are limited due to road connectivity and other climatic issues.

Like other Himalayan states, the state of Himachal Pradesh is also rich in edible plant resources. The rural and tribal people of Himachal Pradesh also utilize wild edibles to meet their food, nutritional and medicinal requirements. In Himachal Pradesh various studies have been conducted by different workers on wild edible plant diversity, distribution and consumption pattern (Rana et al 2012, Sen et al 2013, Sharma and Sood 2013, Singh et al 2014, Negi and Subramani 2015, Lata et al 2016, Thakur et al 2017, Sharma et al 2018 and Paul 2021) in North Western Himalaya of

India. The weather conditions of Kinnaur are very variable, and the region is also home to a wide variety of plants. However, a study on wild edible plants has not been undertaken in the Baspa Valley of district Kinnaur. Therefore, the present study has been conducted to assess diversity, distribution, and utilization patterns and conservation status to suggest management options for the conservation of wild edible plants.

MATERIAL AND METHODS

Extensive and intensive surveys were carried out in Sapni, Barua, Shong, Chansu, Kupa, Kamru, Mone, Batseri, Themgarang, Rakcham and Chhitkul villages of Baspa valley of district Kinnaur of Himachal Pradesh. The study area lies between 31°11′48.13″ N – 31°30′17.16″ N latitudes and 78°06′03.71″ E – 78°52′41.75″ E longitudes (Fig. 1, 2). The elevation range of this valley is 1800 to 5480 m above mean sea level.The valley faces in the directions of northwest to southeast and the river Baspa flows middle of the valley. The valley has alpine, subalpine and temperate vegetation and forests are dominated by *Cedrus deodara,Betula utilis*, *Pinus wallichiana*, *Picea smithiana* and *Abies pindrow* communities and medicinal and aromatic plants, as well as other herbaceous species in sub-alpine and alpine regions. The population of the Baspa valley is approximately 14042 inhabitants comprising 3065 households. For the information collection on wild edible species, oral interviews, personal observations and conversations with locals were used. The locals verbally consented to the transmission of their traditional wisdom (Martin 1995, Collins et al 2006). From each village, knowledgeable persons were interviewed through semi-structured questionnaires. The knowledgeable tribal people were those who have been using wild edible plants for the last 30-40 years. One knowledgeable person was hired from each village for the collection of fresh samples of the wild edible species. The gathered samples were identified using regional using various sources (Nair 1977, Chowdhery and Wadhwa 1984, Polunin and Stainton 1984, Aswal and Mehrotra 1994, Dhaliwal and Sharma 1999 ,Singh and Rawat 2000). All identified species were listed and analyzed for diversity following Samant et al (1998). Index Kewensis and The World Flora Online were followed for nomenclature and nativity (Anonymous 1885) (https://www.worldfloraonline.org). Native species were those that originated or were first reported in the Himalayan region. Species endemism was determined based on species distribution. The species found only in the Himalaya have been regarded as endemic, while those found in adjacent countries were classified as near-endemic (Samant et al 1998 and Rana and Samant 2011).

RESULTS AND DISCUSSION

In the present study, 95 wild edible species belonging to 76 genera and 41 families were recorded from the Baspa valley of district Kinnaur and 86 species belong to angiosperms, 4 to gymnosperms, 2 to pteridophytes and 3 of fungus. These species represented trees (13 spp.), shrubs (21 spp.), herbs (56 spp.), climbers (2 spp.) and fungus (03 spp.). Among families, Rosaceae, Apiaceae and Polygonaceae were dominant families, represented by maximum species (14, 8 and 6 spp., respectively) followed by Asteraceae, Ericaceae and Grossulariaceae and Berberidaceae (04 spp., each), Panaceae and Elaeagnaceae (03 spp., each). Among the genera, *Ribes, Cotoneaster, Rubus, Berberis, Prunus, Utica, Pinus, Viola, Impatiens, Heraclium, Hippophae* and *Allium* were dominant
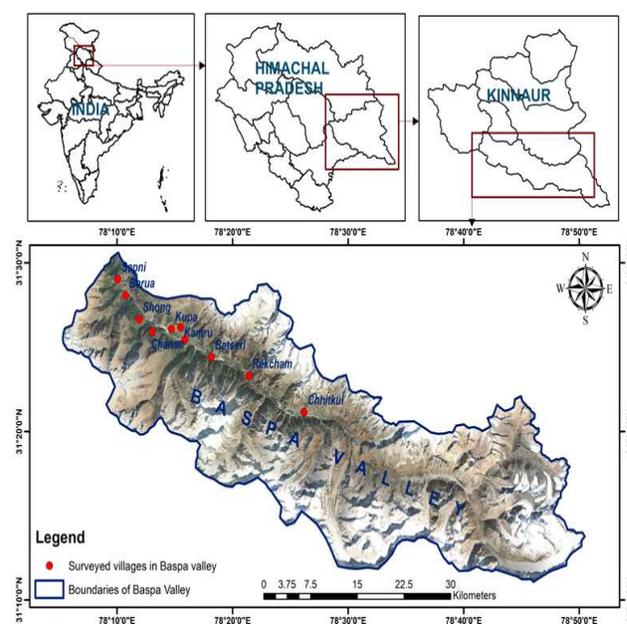
Fig. 1. Baspa valley in Kinnaur district of Himachal Pradesh

Fig. 2. General view of Baspa valley, Kinnaur, Himachal Pradesh

genera. The 38 species were native to the Himalayan region, 11 species native to the Himalayan region and other bio-geographical regions collectively, and the remaining species were not native to the Himalayan region.*Bergenia stracheyi* and *Pinus gerardiana* were endemic and 20 species were near-endemic to the Himalaya (Table 1). Total 39 species were the most preferred and commonly utilized by local tribal communities collected from forest, bounds of agriculture fields and orchards. Besides this, 58 species were also utilized occasionally by tribal communities as per need and availability. Various parts of these plants such as fruits, leaves, stems, flowers, rhizomes, roots, etc., are eaten in either raw or cooked form *i.e.*, boiled, roasted, fried, as flavoring agent or spices, juice, tea etc. (Fig. 3). Amongst the parts used, leaves were the most edible part (34 spp.), followed by fruits, seeds, roots and flowers (Fig. 4).

Amongst the edible species reported eleven species fall under various threat categories. *Dactylorhiza hatagirea* is critically endangered; *Angelica glauca, Dioscorea deltoidea, Podophyllum hexandrum*, *Taxus wallichiana* are endangered and the remaining six species, *Bergenia stracheyi*, *Allium stracheyi, Bunium persicum*, *Ferula jaeschkeana*, *Rhododendron anthopogon* and *Rheum australe* are vulnerable (Ved et al 2003, Anonymous 2010). As per the IUCN Red List, *Angelica glauca, Dactylorhiza hatagirea* and *Taxus wallichiana* are Endangered, (Thomas and Farjon 2011, Ved et al 2015, Chauhan 2022); *Pinus gerardiana* is Near Threatened (Farjon 2013).

The extreme cold and tough geographical condition of the Baspa valley enforces the tribal people to depend on these plants. *Pinus gerardiana, Prunus mira*, *Prunus armeniaca*, *Bhunium persicum, Carum carvi* and *Morchellla esculenta* are the major species having huge market potential also contributes significantly in improving economic conditions of locals. *Pinus gerardiana* is multipurpose tree which contributes significantly in improving livelihood of Kinnaura tribal communities. Locals inhabitants uses Chilgoza as part of various social obligations and also earn money INR 1,500–1,800/ kg by selling the Chilgoza nuts locally and use it for fulfilling their daily household needs (Lata et al 2020). Currently local inhabitants of Kinnaur are also earning INR 1200-1800/ltr by selling seeds oil of Chuli and Bemi in local market. In addition, local women folk also earn INR 1000/-1500/ltr locally by selling traditional liquors (Chul Rak, Regu Rak) obtained from fruits of Chuli and Bemi (Lata et al 2021). The local inhabitants collect Kala-jeera and Mako-jeera during the period June-July from forest and sold in the local market at prices of Rs. 2000/kg and Rs. 500/kg, respectively (Paul 2021; Klate et al. 2023).

This usage of wild edible plants is gradually declining due
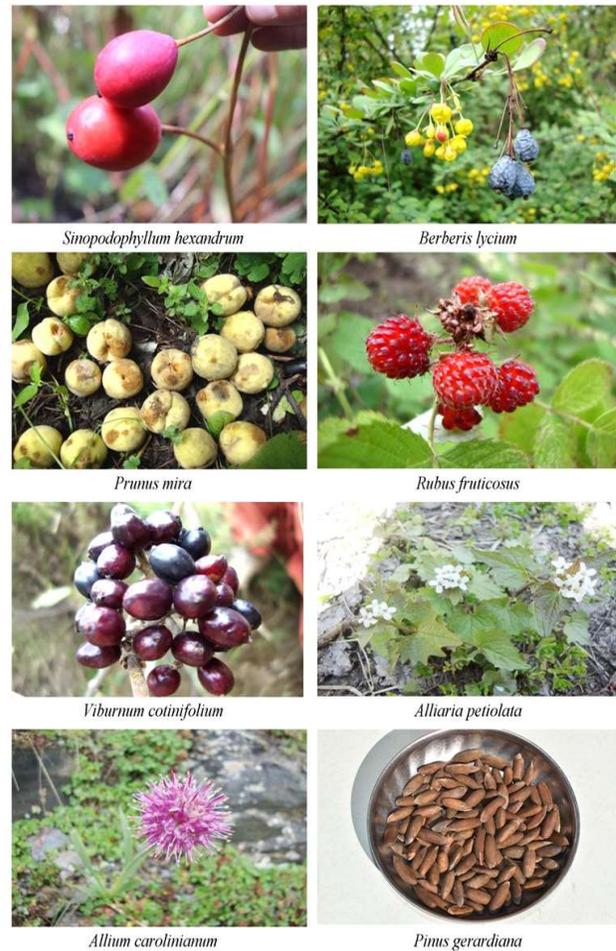
Fig. 3. Some wild edible plants of Baspa Valley in Kinnaur district
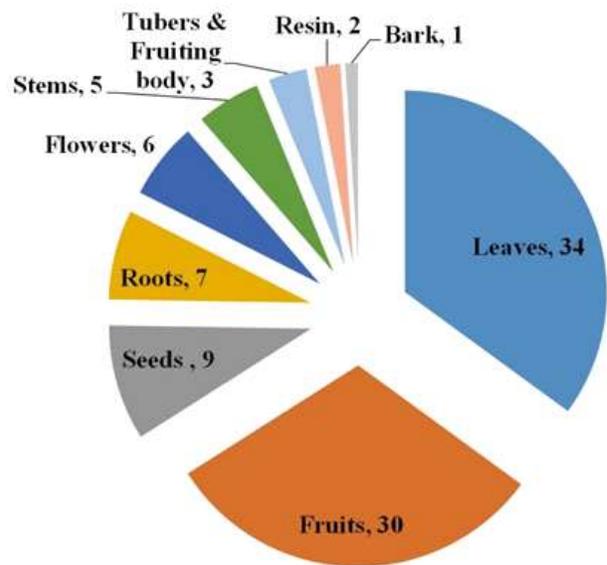
Fig. 4. Part used of wild edible plants of Baspa Valley in Kinnaur district

Table 1. Diversity, local name, indigenous uses and life form of wild edible plants of Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

Taxa	Family	Local Name	Life form	Parts used	Indigenous uses	Nativity
Aesculus indica (Wall. ex Cambess.) Hook. [*]	Sapindaceae	Knor	Tree	Seeds	Seeds flour is used for preparation of roti.	Reg Himal
Agaricus campestris L.	Agaricaceae	Chatri, Mo	Fungus	Fruiting body	Eaten as vegetable.	--
Alliaria petiolata (M. Bieb.) Cavara & Grande	Brassicaceae	--	Herb	Leaves	After boiling leaves are roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Eurasia
Allium humile Kunth	Amaryllidaceae	Kuthae, Jungli Pyzai	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable. Dried leaves are also used as spice in food items.	Ind Or
Allium stracheyi Baker	Amaryllidaceae	Kuthae, Jungli Pyzai	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Himal
Angelica glauca Edgew.	Apiaceae	Chora, Sapal	Herb	Roots	Root powder is used as a spice in food items. Root is also used to cure stomach related problems.	Reg Himal
Arisaema jacquemontii Blume [*]	Araceae	Jamashang	Herb	Tubers	After fermentation tubers used for preparation of traditional alcoholic beverage 'Jamashang'.	Reg Himal
Artemisia scoparia Waldst. & Kitam	Asteraceae	--	Herb	Stem	Decoction of the stem used to cure hair related problems.	Europe Oriens Ind Or
Berberis aristata DC. [*]	Berberidaceae	Chutrum	Shrub	Fruits	Riped fruits are eaten. Decoction of roots also used to cure eye problem.	Reg Himal
Berberis asiatica Roxb. ex DC.	Berberidaceae	Chutrum	Shrub	Fruits	Riped fruits are eaten. Decoction of roots also used to cure eye problem.	Reg Himal
Berberis lycium Royle[*]	Berberidaceae	Chutrum	Shrub	Fruits	Riped fruits are eaten. Decoction of roots also used to cure eye problem.	Reg Himal
Bergenia stracheyi (Hook.f. & Thomson) Engl.[**]	Saxifragaceae	Rachukanang	Herb	Leaves	Leaves are chopped and mixed with gram flour and spices by adding water and eaten as pakoras by frying in oil.	Reg Himal Mexico Amer
Bistorta affinis (D.Don) Greene [*]	Polygonaceae	Susilang	Herb	Seeds	Raw seeds are eaten.	Reg Himal
Bunium persicum B.Fedtsch	Apiaceae	Kala-jeera	Herb	Seeds, Tubers	Decoction of the seeds used to cure stomachache. Seeds also used as spice in food items. Root tubers eaten after proper cleaning.	Persia
Cannabis sativa L.	Cannabaceae	Sulfa	Herb	Leaves	Leaves are mixed with gram flour and spices by adding water and eaten as pakoras by frying in oil.	As Centr Reg Himal Bor Occ
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	Tiskan	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Temp
Cardamine impatiens L.	Brassicaceae	--	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Europe As
Carum carvi Linn	Apiaceae	Mako zeera	Herb	Leaves, Seeds, Roots	Decoction of the seeds used to cure stomachache, leg pain and leukorrhea. Seeds also used as spice in food items.	Europe As Bor

Table 1. Diversity, local name, indigenous uses and life form of wild edible plants of Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

Taxa	Family	Local Name	Life form	Parts used	Indigenous uses	Nativity
Cassiope fastigiata (Wall.) D.Don*	Ericaceae	Tishur	Herb	Flowers	Flowers are dried and used in salted tea preparation. Decoction of flowers also used to cure stomach related problems.	Reg Himal
Cedrus deodara (Roxb. ex D. Don) G Don*	Pinaceae	Kyalbang	Tree	Resin	Resin chewed for stronger gums.	Reg Himal
Celtis australis L.	Ulmaceae	Kharak, Kru	Tree	Fruits	Riped fruits eaten.	Europe As Temp Ind Or
Chaerophyllum villosum Wall. & DC	Apiaceae	--	Herb	Roots	Roots are eaten.	Reg Himal
Chenopodium album L.	Chenopodiaceae	Bathua	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Temp et Trop
Cicer microphyllum Royle ex Benth.	Fabaceae	--	Herb	Seeds	Seeds are eaten.	Soongar Reg Himal Bor Occ
Cirsium wallichii var. *glabratum* (Hook. f.) Wendelbo*	Asteraceae	Tee cho	Herb	Roots	After boiling in water roots are eaten.	Reg Himal
Cotoneaster bacillaris Wall. ex Lind*	Rosaceae	--	Shrub	Fruits	Ripe fruits are eaten.	Reg Himal
Cotoneaster microphyllus Wall. ex Lindl.	Rosaceae	--	Shrub	Fruits	Ripe fruits are eaten.	Reg Himal
Cotoneaster nummularius Fisch.& C.A.Mey.	Rosaceae	--	Shrub	Fruits	Ripe fruits are eaten.	Afr Bor Oriens
Cousinia thomsonii C.B.Clarke*	Asteraceae	Tee cho	Herb	Roots	After boiling in water roots are eaten.	Reg Himal
Cuscuta reflexa Roxb.	Convolvulaceae	Amarbel	Climber	Stem	Decoction consumed to cure blood related problems.	Ind Or
Dactylorhiza hatagirea (D.Don.) Soo*	Orchidaceae	Salampanja	Herb	Roots	Tubers eaten to cure sexual debility.	Europe Afr Bor Oriens Reg Himal
Dioscorea deltoidea Wall.ex Griseb.	Dioscoreaceae	Singli-Mingli	Climber	Tubers	Tubers boiled and fried in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	As Trop
Diplazium esculentum (Retz.) Sw.	Dryopteridaceae	Lingad	Herb	Curled fronds	Fronds are chopped into small pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Himal
Dipsacus inermis Wall.	Dipsacaceae	Tis kan	Herb	Leaves	Leaves eaten as vegetable.	Reg Himal
Elaeagnus parvifolia Wall. ex. Royle	Elaeagnaceae	Ral, Ralla	Shrub	Fruits	Riped fruits eaten.	Japan
Equisetum arvense L.	Equisetaceae	Kinang, Paccu	Herb	Fertile Stem	Young shoots edible.	--
Eremurus himalaicus Baker*	Liliaceae	Yam Kan	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Himal
Fagopyrum acutatum Mansf. ex. K Hammer	Polygonaceae	Jungli Olgo Kan	Herb	Leaves	The leaves are cut into smaller pieces and roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Himal China
Ferula jaeschkeana Vatke	Apiaceae	Kedmo, Sapal	Herb	Roots	Root powder used as spice in food items. Root also used to cure stomach related problems.	Himal Bor Occ Turkestan
Fragaria nubicola (Lindl. ex Hook.f.) Lacaita	Rosaceae	Babashoch	Herb	Fruits	Riped fruits eaten.	Ind Or Sikkim

Table 1. Diversity, local name, indigenous uses and life form of wild edible plants of Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

Taxa	Family	Local Name	Life form	Parts used	Indigenous uses	Nativity
Gaultheria trichophylla Royle	Ericaceae	--	Shrub	Fruits	Riped fruits eaten.	Reg Himal
Girardinia diversifolia (Link) Friis	Urticaceae	Bogthor, Khorgya	Herb	Leaves	The leaves are cut into smaller pieces and boiled in water by adding salt, chilly, onion and garlic, seed paste of wild apricot and eaten as vegetable.	Ind Or Malaya
Heracleum candicans Wall. ex DC.	Apiaceae	Poryal	Herb	Shoots	Tender shoots eaten with curd.	Reg Himal Ind Or As Trop
Heracleum pinnatum C.B. Clarke	Apiaceae	Hungshuli	Herb	Shoots	Young shoots eaten as vegetable.	Reg Himal
Hippophae salicifolia D.Don[*]	Elaeagnaceae	Surch, Surchu	Shrub	Fruits, Leaves	Riped fruits are eaten and juice is also prepared. Dried fruits and leaves also used for preparation of tea.	Reg Himal
Hippophae tibetana Schltdl.	Elaeagnaceae	Surch, Surchu	Shrub	Fruits, Leaves	Riped fruits are eaten and juice is also prepared. Dried fruits and leaves also used for preparation of tea.	Europe As Temp
Impatiens glandulifera Royle.	Balsaminaceae	Ticktoc	Herb	Seeds	Seeds edible.	Reg Himal
Impatiens sulcata Wall.[*]	Balsaminaceae	Ticktoc	Herb	Seeds	Seeds edible.	Reg Himal
Indigofera heterantha Wall. ex Brandis	Fabaceae	Kasting	Shrub	Flowers	Eaten as vegetable.	Reg Himal
Juglans regia L.[*]	Juglandaceae	Ka	Tree	Nuts/Seeds	Nuts edible and seed paste also used for preparation of salted tea.	As Occ Reg Himal
Lectuca dolichophylla Kitam.	Asteraceae	--	Herb	Leaves	Eaten as vegetable.	Reg Himal
Lepidium latifolium L.	Brassicaceae	Tis kan	Herb	Leaves	Eaten as vegetable.	Europe As Bor Oriens
Malus baccata (L.) Borkh.	Rosaceae	Khontli	Tree	Fruits	Riped fruits eaten.	Reg Himal As Bor
Malva verticillata L.	Malvaceae	--	Herb	Leaves	Leaves eaten as vegetable.	Europe As et Afr Bor
Medicago falcata L.	Ericaceae	--	Herb	Leaves	Tender leaves used as vegetable.	Geront Bor Temp
Mentha longifolia (L.) L.	Lamiaceae	Horsemint	Herb	Leaves	Leaves used for preparation of tea.	Reg Bor Temp
Morchella esculenta Fr.	Morchellaceae	Rangmoch, Zangmoch	Fungus	Fruiting body	Fruiting bodies is properly cleaned and roasted in oil by adding spices. Soup is also prepared form it which is used to cure body weakness, loss of appetite and leg pain.	--
Nasturtium officinale R.Br.	Brassicaceae	Bolku	Herb	Leaves	The leaves are cut into smaller pieces and fried in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Ind Or China
Origanum vulgare L.	Lamiaceae	Ban ajwain	Herb	Leaves	Leaves used for preparation of tea and chutney.	Europe As et Afr
Oxalis corniculata L.	Oxalidaceae	Indian sorrel, Khatti-mithi	Herb	Leaves	Leaves used for preparation of chutney.	Amphig Temp et Trop
Oxyria digyna (L.) Hill	Polygonaceae	Shupchu	Herb	Leaves	Eaten raw or cooked.	Reg Bor Alp et Arct
Phytolacca acinosa Roxb	Phytolacaceae	Zorbo	Herb	Leaves	The leaves are cut into smaller pieces and fried in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Himal, China

Table 1. Diversity, local name, indigenous uses and life form of wild edible plants of Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

Taxa	Family	Local Name	Life form	Parts used	Indigenous uses	Nativity
Pinus gerardiana Wall.ex D.Don**	Pinaceae	Neoza, Ree	Tree	Seeds	Raw and roasted seeds are eaten as dry fruit. Garlands prepared from seeds used to express love and respect to relative, guest and deities. Seed paste also used for preparation of salted tea.	Reg Himal
Pinus wallichiana A.B. Jacks	Pinaceae	Lim	Tree	Resin	Resin chewed for stronger gums.	Reg Himal
Plantago depressa Willd.	Plantaginaceae	--	Herb	Leaves	Tender leaves are eaten as vegetable.	Sibir
Polygonum molle D. Don	Polygonaceae	--	Herb	Stem	Tender stem edible.	Reg Himal
Prunus armeniaca L.	Rosaceae	Chul	Tree	Fruits	Fruits are eaten raw or after drying in sun. Fruits used for the preparation of traditional alcoholic beverage Rak or Arak' which is generally consumed by locals in marriages and festive occasions and also used for worshipping deities. Fruits eaten with 'Sattu' by preparing special dish 'Chul Phanting'. Seeds paste boiled with rice by adding salt and eaten as 'Remo thukpa'. Garlands prepared from seeds used to express love and respect to relative, guest and deities.	Reg Caucas
Prunus cornuta (Wall. ex Royle) Steud	Rosaceae	Krun	Tree	Fruits	Riped fruits eaten.	Ind Or
Prunus mira Koehne	Rosaceae	Reg	Tree	Fruits	Fruits are eaten raw. Fruits used for the preparation of traditional alcoholic beverage Regu Rak' which is generally consumed by locals in marriages and festive occasions and also used for worshipping deities. Seeds paste boiled with rice by adding salt and eaten as 'Remo thukpa'. Garlands prepared from seeds used to express love and respect to relative, guest and deities.	China
Pyrus pashia Buch.-Ham. ex D.Don	Rosaceae	Kainth	Tree	Fruits	Riped fruits eaten.	Reg Himal
Ramaria abietina(Pers) Quel.	Gomphaceae	Chayen	Fungus	Fruiting body	Fruiting bodies is properly cleaned and roasted in oil by adding spices.	--
Rheum australe D.Don	Polygonaceace	Aarch, Archa, Chuchi	Herb	Leaves	Used for making chutneys.	Reg Himal
Rhododendron anthopogon D.Don	Ericaceae	Peek Saimanang, Mutik	Herb	Flowers	Used for preparation of tea.	Ind Or Reg Himal Zeylan
Ribes alpestre Wall. ex Decne.	Grossulariaceae	Cho Shoch	Shrub	Fruits	Riped fruits eaten.	Europe Afr Bor Reg Himal China
Ribes glaciale Wall.	Grossulariaceae	Rang shoo	Shrub	Fruits	Riped fruits eaten.	Reg Himal
Ribes himalense Royle ex Decne	Grossulariaceae	Khali Shoch	Shrub	Fruits	Riped fruits eaten.	China

Cont...

Table 1. Diversity, local name, indigenous uses and life form of wild edible plants of Baspa Valley, Kinnaur, Himachal Pradesh, North Western Himalaya, India

Taxa	Family	Local Name	Life form	Parts used	Indigenous uses	Nativity
Ribes orientale Desf.	Grossulariaceae	Cho Shoch	Shrub	Fruits	Riped fruits eaten.	Reg Himal
Ribes rubrum L.	Grossulariaceae	Ralashoo	Shrub	Fruits	Riped fruits eaten.	
Rosa macrophylla Lindl.*	Rosaceae	Rose, Lama uh.	Shrub	Fruits	Riped fruits eaten.	Reg Himal, China
Rubus niveus Thunb.	Rosaceae	Roksoch	Shrub	Fruits	Riped fruits eaten.	Reg Himal
Rubus ellipticus Sm.	Rosaceae	Hinsar, Choshoch	Shrub	Fruits	Riped fruits eaten.	Ind Or
Rubus fruticosus Hegetschw.	Rosaceae	Blackberry, Chosho	Shrub	Fruits	Riped fruits eaten.	Europe
Rumex nepalensis Spreng.	Polygonaceae	Jungli Palak	Herb	Leaves	Tender leaves eaten as vegetable.	As Occ Ind Or Malaya AfrAustr
Silene vulgaris (Moench) Garcke	Caryophyllaceae	Shoshor	Herb	Leaves	Leaves are roasted in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Europe, Temp Asia and Northern Africa
Podophyllum hexandrum Royle	Berberidaceae	Bankakdi	Herb	Fruits	Riped fruits eaten.	Ind Or As Trop
Solanum nigrum L.	Solanaceae	Black Night Shade, Makoi	Herb	Fruits	Riped fruits eaten.	Trop Geront
Sorbus lanata (D.Don) S.Schauer	Rosaceae	Bolu	Tree	Fruits	Riped fruits eaten.	Reg Himal
Taraxacum officinale F.H.Wigg.	Asteraceae	Bitterwort, Kan	Herb	Leaves	Tender leaves and flowers are chopped into small pieces and fried in oil by adding salt, chilly, onion and garlic and eaten as vegetable.	Reg Temp Bor et Austr
Taxus wallichiana Zucc.	Taxaceae	Sang cha	Tree	Bark	Bark is boiled in water by adding salt, milk and butter and taken as salted tea 'Cha Cha'.	Reg Himal
Thymus linearis Benth.	Lamiaceae	Ban Ajwain	Herb	Leaves	Used for preparation of tea and chutney.	Europe As et Afr BorHispan
Urtica dioca L.	Urticaceae	Bichu-buti, Choya	Herb	Leaves	The leaves are cooked in water by adding salt and paste of wild apricot.	Reg Bor Temp
Urtica hyperborea Jacq. ex Wedd.	Urticaceae	Bichu-buti, Choya	Herb	Leaves	The leaves are cooked in water by adding salt and paste of wild apricot.	Reg Himal
Viburnum cotinifolium D. Don*	Caprifoliaceae	Sussu, Tustus	Shrub	Fruits	Riped fruits eaten.	Reg Himal
Viola biflora L.	Violaceae	Banaksha	Herb	Flowers	Flowers eaten to cure fever.	Reg Bor Temp
Viola serpens Wall. ex Ging.	Violaceae	Banaksha	Herb	Flowers	Flowers eaten to cure fever.	Reg Himal

Abbreviations used: **= Endemic; *= Near endemic; Reg=Region; Himal=Himalayan; Amer=America; Bor=Boreal; Temp=Temperate; Centr=Central; As=Asia; et=And; Trop= Occ=Occidentalis; Or=Oriental; Caucas=Caucasus; Ind=Indian; Afr=Africa; Trop=Tropical; Amphig=Amphigaea; Alp=Alpine; Arct=Arctic; Geront=Gerontia; Sibir=Siberia; Austr=Australia

lack of usage knowledge among younger generation as they are showing more interest in tourism and horticulture and in most of the areas the traditional knowledge and practice of these species has been remained restricted only to the elder people. Currently, continuously changing climatic conditions coupled with anthropogenic factors such as unsustainable harvesting practices, construction of hydropower projects, roads, buildings, tourism activities and horticultural expansion affecting natural population of wild edible plants. Along with these modernizations, westernization, migration of local inhabitants in cities for education of children and jobs etc., are also contributing towards the lesser utilization of edible wild plants.

Baspa valley represents a rich diversity of wide edible

plant plants which has huge potential in supplementing the food requirements of local inhabitants and reducing the susceptibility to food insecurity especially during drought and other adverse calamitic conditions. The climatic conditions of Baspa valley is harsh and the majority of the area of valley remains disconnected with outside world especially during winter time due to heavy snow fall. Due to which locals do not have year-round access as well as consistent availability and supply of food resources like other parts of the state hence people are forced to utilize these available wild plants in dried or preserved forms when fresh vegetable and fruits are not available.

CONCLUSIONS

Present study provides detailed information on diversity, indigenous uses, distribution pattern, threat status and utilization pattern of wild edible plants used by inhabitants of Baspa Valley. Inventory of 95 wild edible species belonging to 14 families and 76 genera, mostly represented by herbs indicated unique utilization pattern. These wild plants contribute significantly in supplementing the food requirements of local inhabitants in tough climatic conditions especially in winters when entire area is covered with snow. The usage of endemic (2 species) and near endemic (20 species) and threatened plants (15 species) also shows high conservation value. Therefore, population assessment, habitat monitoring, development of sustainable harvesting methods, awareness and field demonstration programmes on sustainable harvesting methods for inhabitants, development of cultivation techniques through conventional and in vitro methods, establishment of germplasm banks, evaluation of nutraceutical potential and value addition for livelihood support suggested for conservation and sustainable management suggested.

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Prediction of Risk Zones and Wildlife Exposure Assessment in Periyar Tiger Reserve using Machine Learning Approach in Kerala, India

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Abstract: Forests are extremely risky and these risks frequently cause animals to go extinct. Similar to other hilly regions, the Periyar Tiger Reserve is habitat to a variety of natural hazards and animal-human interactions, although it is unclear how the risk areas are spread or how the exposed species are distributed. The high-resolution trans boundary models illustrating risk to floods, landslides, wildfires, and human-wildlife interactions is proposed in order to assess wildlife distribution vulnerability to high-risk zones across the Periyar Tiger Reserve. An inventory map of the first Using field surveys and various official data, four different types of risks flood, landslides, forest fires, and Human wildlife conflict were created. Using the Max Ent (Maximum Entropy) machine learning technique, a total of 13 geo-environmental parameters were chosen as predictors to create the risk maps. Generating receiver operating characteristic (ROC) curves and computing the area under the ROC curve (AUCROC) allowed us to assess the predictive models' accuracy. The Max Ent model not only performed exceptionally in terms of degree of fitting but also produced significant results in terms of predictive performance. Indicators of the relative relevance of the four categories of risks under study revealed that elevation and distance from streams were, two most crucial determinants for flooding. For detecting landslides, soil, topographic roughness index, and forest cover were important factors. The closest roads, the amount of forest cover, and livestock were each ranked as the three most crucial determinants for human-wildlife conflict. The research area's annual mean temperature, elevation and distance from water bodies, as well as the presence of livestock, were key factors in the mapping of forest fires. An integrated multi-hazard map was finally produced by merging the high-risk zones for flood, landslides, wildfire, and Human wildlife conflict risk. The results demonstrated that 55 % of the area is subjected to risks, reaching a proportion of landslides up to 31%, human wildlife conflict up to 9%, flood up to 5% and fire up to 10 % in the whole territory. Human settlements in the Periyar Tiger Reserve are disproportionately concentrated in areas of high risk. In contrast, low-risk areas are disproportionately unpopulated. Nearly half of Tiger population in the region lives in areas that are highly susceptible to landslide. Few percentages of elephant population live in areas that are highly suspect able to human wildlife conflict zones. Fire and flood risk areas suspect able to the wildlife is comparatively less. Using this type of multi-hazard map may be a useful tool for local administrators to identify areas susceptible to hazards at large scales as we demonstrated in this research.

Keywords: Risk map, Machine Learning algorithms, Periyar Tiger reserve, Wildlife exposure

The IPCC's 6th Assessment Report highlights the profound impact of climate change, particularly in mountain regions, where increased warming and extreme precipitation are expected to lead to cascading consequences such as floods, landslides, and other hazards. Mountainous areas, while providing essential resources to downstream regions, also face significant vulnerability due to their topography, geological processes, and hydrological characteristics (IPCC 2021). Globally, mountain regions account for a majority of hazard-related fatalities, underscoring the urgency of addressing multi-hazard risks in these areas. Agenda 21, established in 1992, emphasizes the importance of sustainable mountain development, stressing the need for risk evaluation and mitigation strategies. With mountain populations growing and urbanizing, the need for effective hazard management is more pressing than ever.

In the Western Ghats, forest fires are a frequent natural disturbance, especially during the summer months. Geospatial techniques have been employed to identify and map fire risk zones in the Periyar Tiger Reserve. Factors such as land cover type, slope, distance from settlements and roads, and elevation were considered in this study. The resulting Fire Risk Index methodology categorizes the area into five risk zones, verified using historical fire incidence data. This risk zone map provides valuable insights for resource managers and planners to implement effective mitigation measures (RS Ajin et al 2015). Similarly, studies in other regions such as Iran and Austria have utilized advanced machine learning techniques to produce multi-hazard risk maps for floods, landslides, wildfires, and other natural events. These maps, derived from comprehensive environmental data and predictive models, offer crucial

information for risk management and disaster mitigation efforts. By integrating hazard susceptibility mapping with land use planning, these studies aim to reduce vulnerability and enhance resilience in hazard-prone areas (Soheila Pouyan et al 2021).

In the Kangchenjunga Landscape, efforts have been made to map human-wildlife conflict hotspots using Max Ent coupled with relevant environmental variables. These hotspots, identified based on factors like road proximity and protected area fragmentation, highlight the need for landscape-level approaches to mitigate conflicts between humans and wildlife. Restoring fragmented habitats and implementing comprehensive conservation strategies are essential steps in addressing human-wildlife conflicts and ensuring the coexistence of both populations (Prashanti Sharma et al 2020). For the Periyar Tiger Reserve in Kerala, there is a crucial need to map risk zones and assess wildlife exposure, particularly concerning landslides, wildfires, floods, and human-wildlife conflict. This research endeavour will provide vital information for policymakers and planners to identify high-risk areas and implement effective mitigation measures, ultimately enhancing the resilience of both ecosystems and communities. The objectives are to identify and prioritize factors influencing flood, forest fire, landslide, and human-wildlife conflict risk zones. Separate maps for each risk zone using the Max Ent algorithm will be created, along with a map of the Tiger Reserve's risk hotspots. Additionally, understanding wildlife distribution, especially mammal exposure to high-risk zones, is a key goal.

MATERIAL AND METHODS

Study area: Periyar Tiger Reserve, located in the Cardamom and Pandalam Hills of the Southern Western Ghats, spans latitudes 9° 17' 56.04" to 9° 37' 10.2" N and longitudes 76° 56' 12.12" to 77° 25' 5.52" E. It falls within Idukki, Kottayam, and Pathanamthitta Districts of Kerala. Established in 1950 as the Periyar Wildlife Sanctuary, it was designated as a Tiger Reserve in 1978, covering 925 km2, with 881 km2 as core habitat and 44 km2 as buffer (Fig. 1). It harbors significant biodiversity, hosting 41% of Kerala's flowering plants, including 26% endemic to the Southern Western Ghats. The reserve supports a variety of flora and fauna, including 17 possibly extinct species and unique plants like Habenaria periyarensis. With over 350 medicinal plant species and endangered fauna such as tigers, elephants, and lion-tailed macaques, it is vital for conservation. Periyar is home to 66 mammal species, 342 bird species, and diverse reptiles, amphibians, fishes, and butterflies. It serves as a critical link in maintaining forest connectivity in the Western Ghats. The park experiences an average rainfall of 914mm to 2010mm

and temperatures ranging from 15 to 30 degrees Celsius, with its highest point at 2017 meters above sea level. Vegetation includes evergreen, deciduous, and semi-evergreen forests, as well as grasslands. It is traversed by NH 183, connecting Theni in Tamil Nadu to Kollam in Kerala.

Data and methods: All hazard instances were recorded as points and environmental covariates were continuous or categorical raster layers. Geographic patterns in hazard locations are summarized in Figure 2. Variables used are summarized in Table 1. Periyar Tiger conservation foundation provided data for the years 2001-2021. In this study, however, only 56 spatiotemporally independent fire incidents, 20 flood incidents, 17 conflict locations and 9 landslide locations were used to create the model. After testing the spatiotemporal data using the software package Diva GIS, the auto-correlated sites were eliminated (DIVA GIS version 2). If more than one observation was aggregated in a grid, only one location per 1 km grid cell was used (i.e., to avoid autocorrelation with low sample size).
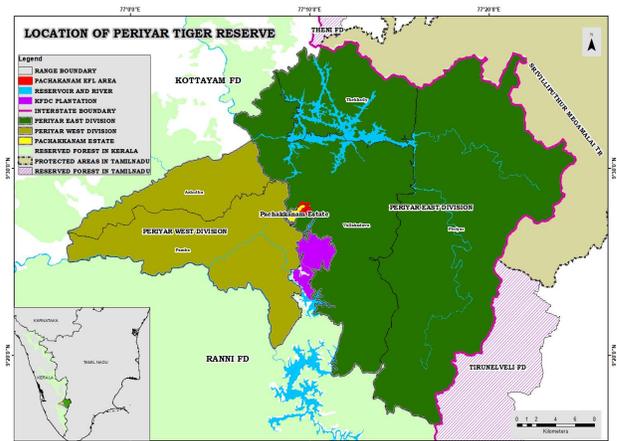
Fig. 1. Location of study area
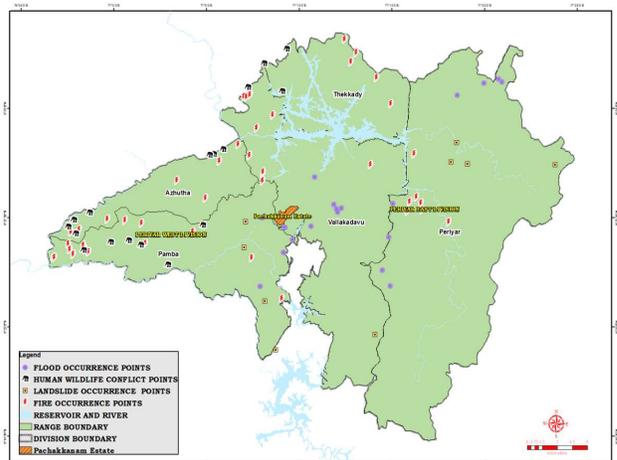
Fig. 2. Hazard locations map (Last 20 years)

Digital elevation model: Topography plays a crucial role in shaping hazard-prone environments, with eleven topographic environmental factors considered: elevation, slope, aspect, terrain wetness index, terrain position index, terrain ruggedness index, stream power index, LS factor, plan curvature, profile curvature, and flow accumulation. These factors influence water movement and soil stability, commonly incorporated into hazard models assessing flood and landslide susceptibility. The digital elevation model (DEM) utilized is from ALOS PALSAR DEM (2014), obtained through radar interferometry with a 12.5m resolution, overcoming cloud cover limitations in the study area. ALOS PALSAR data and its derivatives have been instrumental in hazard assessments for flooding, forest fires, landslides, and human-wildlife conflict in PTR. Slope is determined by the highest magnitude first derivative across each cell of the ALOS PALSAR DEM, while aspect denotes the down slope direction. Flow accumulation measures the number of cells upslope from any given cell, crucial for understanding water movement through watersheds. Topographic wetness index quantifies terrain-driven variation in soil moisture, aiding in hazard prediction. Topographic position index helps distinguish topographic features, while terrain ruggedness index expresses elevation differences between adjacent cells. Stream power index estimates the erosive power of flowing water, predicting potential gully formation. The LS-factor combines slope length and steepness, reflecting soil loss. Profile curvature indicates the direction of maximum slope, affecting flow acceleration or deceleration, while plan curvature reflects the curvature of contours, influencing water flow direction. These variables were derived using ArcGIS 10.3.

Normalized differential vegetation index: The normalized difference vegetation index (NDVI), which is derived from remote-sensing (satellite) data, is closely linked to drought conditions. To determine the density of green on a patch of land, the distinct colours (wavelengths) of visible and near-infrared sunlight reflected by the plants are observed. Range of NDVI is −1 to +1. Higher value of NDVI refers to healthy and dense vegetation. Lower NDVI values show sparse vegetation. The Normalized Difference Vegetation Index is prepared by using Sentinal-2 images where band 8 is Near Infrared and band 4 is Red. The NDVI can be calculated from,

$$NDVI = ((BAND8 - BAND4)/(BAND8+BAND4))$$

Forest cover: Forest cover is a significant factor in forming hazard-prone environments and is often integrated into susceptibility models (Rimal et al 2015, Aryal et al 2020, Vilà-Vilardell et al 2020). In the PTR, forest cover is classified into categories such as moist deciduous forest, evergreen and semi-evergreen forest, thickets, grassland, and water bodies. Classification was conducted using a supervised algorithm on Sentinel-2 imagery, with 70% of the ground truth dataset used for classification and 30% for testing. The overall accuracy of the classification process was determined to be 95.57% (Veeramani et al 2023).

Lithology and fault: The dominant rock types in the Mullaperiyar region, forming the core and buffer areas of the PTR, are Precambrian crystalline rocks, primarily the Charnockite-Khondalite–migmatite complex. Charnockite is prevalent, with hornblende gneiss in the eastern side. The gneissosity trend varies from WNW-ESE to NE-SW, exhibiting symmetrical and asymmetrical antiforms and

Table 1. Predictor variables tested for prediction modelling of various Risk in PTR

Data description	Type	Source	Derived Layers
Sentinel-2 -10 m	Raster	USGS Earth Explorer	NDVI
ALOS PALSAR-DEM-12.5 m	Raster	Alaska Satellite Facility-Vertax	Elevation, Slope, Aspect, Accumulation, TRI, Plan curvature, Profile Curvature, TPI, TWI, SPI, LS factor
Annual Temperature	Raster	Periyar tiger conservation foundation	
Annual Precipitation	Raster	Periyar tiger conservation foundation	
Forest Cover	Raster	FSI-2019	Sentinel-2
Soil Suborder	Raster	FAO-UNESCO,2005	
Lithology	Raster	GSI, India	
Water body	Raster	SOI TOPOSHEET	Distance from Water Source
Settlements	Raster	SOI TOPOSHEET	Distance from Settlements,
Linear networks	Raster	SOI TOPOSHEET	Distance from Roads, Trekpath, Power lines
Faults	Raster	SOI TOPOSHEET	Distance from faults
Streams	Raster	SOI TOPOSHEET	Distance from Streams
Livestock	Raster	https://livestock.geo-wiki.org/ home-2/	1*1 km Grid

synforms, with an observed overturned and refolded antiformal structure in the central area, passing through Mullaperiyar. Major crustal discontinuities include the NW-SE trending Muvattupuzha fault, WNW-ESE trending Achankovil shear zone, and NNW-SSE striking Udumbanchola fault. Visible lineaments around the reservoir contribute to the shape of Periyar Lake, reflecting topographic lows and valleys. The lake's EW shape with arms oriented towards NNW, NE, and north correlates with these lineaments. The area exhibits a higher lineament density compared to adjacent parts, indicating significant past tectonic activity, with the Udumbanchola and Cumbam faults intersecting in the reservoir area.

Soil: The properties of a soil affect its contribution to hazard-forming environments. For example, the shear strength of a soil is a property related to its propensity to slide, and a soil suborder's permeability affects how water moves through its matrix of or over its surface. In these models, FAO-UNESCO world soil suborder data were included as a categorical covariate at a resolution of 0.033 decimal degrees. This soil map is not remotely sensed, but is based on ground surveys and national data. Soil moisture is related to the incidence of landslides and floods. High soil moisture lowers the shear strength of a soil, preconditioning slope failure and land sliding, and increases surface runoff, in turn increasing peak flow and flooding (Wasko and Nathan 2019). Soil moisture data for the study region at a 15-km resolution was obtained from those published by the European Space Agency's Climate Change Initiative. These data represent the average annual soil moisture values in volumetric water content (m3/m3) from 1991 to 2016.

Distance to settlement: The 44 sq.kms of forest types in Buffer zone encompasses Human settlement, leased area, office buildings and other supporting facilities for tourism and education and awareness. There are 3 tribal settlements in the buffer zone of PTR (East). Apart from these settlements there are no other settlement inside PTR, East Division. Five EDC-Eco Development Committee are operating in these three tribal settlements (Table 2).

Distance to waterbody: Fluvial flooding occurs when a water body exceeds its capacity and floods its adjacent area, and thus has a direct relationship with the distance from a water body. Each cell in the study region was assigned a value describing its distance in decimal degrees to the nearest permanent water cell. Permanent water was defined as water that occurred more than 85% of the time. These data were derived from the Global Surface Water Explorer, a dataset that quantifies global surface water changes between 1984 and 2015 at 30-meter resolution (Pekel et al 2016). These data are commonly cited in models of hydrologic hazards in the PTR

(Mohanty and Maiti 2021, Veh et al 2019).

Distance to streams: Many streams feeding the two major rivers *viz*. Periyar and Pamba are perennial. Unlike the streams in the evergreens above 1000m, some of the streams feeding Pamba and Azhutha dry up in peak summer. Except for a few, the marshes and streams on the grassy hill tops around the lake also dry up. The water level in lake fluctuates between a maximum of 41.5m (136 feet at the full reservoir level) to a minimum of 32m (104.9869 feet). A number of bunds, check dams and artificial pools have been made over the years, which hold water even during peak summer. Water sources along the traditional pilgrim routes are used by a large number of pilgrims during the pilgrimage season. The water of Pamba below Sabarimala becomes severely polluted due to human waste by the end of the pilgrim season in January. People as well as livestock utilize some of the water sources near Thekkady. The canal leading from the reservoir to the pen-stoke is put to variety of uses like bathing, washing etc. The check dam prevents the effluents from Kumily town from seeping into the reservoir. However, during heavy rains the check dam overflows into the canal. Part of the reservoir in buffer is utilized for providing boating facilities for tourists. Since the India Eco-development Project, fishing by tribes is regulated. In addition, the lake meets the water needs of people of Kumily.

Distance to Road: There are two major roads present inside the park which is given below

a) Kozhikanam - Aruvioda and Zero - Pachakkad roads and culverts are to be maintained.

b) The existing Meenar coupe road is to be maintained and culverts reconstructed in order to patrol even during monsoon season.

Distance to power line: There are 4 high tension power line passing through Periyar East Division. Details of power line is given in (Table 3). There is always a risk of fire occurrence from these transmission lines.

Precipitation and temperature: The Tiger Reserve experiences two distinct monsoon seasons with highly variable rainfall patterns across the area. Maximum recorded rainfall reached 5803 mm at Pachakanam in 2007, while the lowest was 1145 mm at Thannikudy in 2010. About two-thirds of the total rainfall occurs during the southwest monsoon from June to September, while the northeast monsoon

Table 2. Settlements within PTR east division

Settlements	Community	No. of families	No. of members
Labbakandam (Mannakudy)	Mannan tribe	327	1268
Labbakandam (Paliyakudy)	Paliyan tribe	153	453
Vanchivayal	Urali tribe	74	264

typically lasts from October to December, influencing management strategies. July is the wettest month, with January being the driest. December to April is generally considered the dry season, with temperatures ranging from 11°C to 27°C. The hottest months are April and May, while December and January are the coolest. Lowest humidity is observed from February to April. Dew formation in December-January keeps vegetation green, particularly grass. The South-West monsoon brings maximum wind velocity. The reserve has two major rivers with perennial feeder streams and reservoirs, ensuring water availability year-round. Severe drought, experienced in 1983, led to extensive forest fires. Some streams feeding the major rivers may dry up in peak summer, along with marshes and streams around the lake, although water levels are regulated between 41.5 m and 32 m through bunds, check dams, and artificial pools, ensuring water retention even in peak summer.

Environmental covariate data resampling: Raster grids for all environmental data were resampled to 16 arcsecond (approximately 0.5 km) resolution. Continuous covariates were resampled using bilinear interpolation. Soil suborder was up sampled by assigning the value of the original larger cell to each new smaller cell within its bounds. Land cover was down sampled by assigning each new cell the most common value of the original cells within its bounds.

Wildlife distribution data: The distribution of tigers and elephant is collected using the 8-day protocol exercise and also during regular perambulation by frontline staff. Status of distribution of the carnivores is also being analyzed annually based on the sign survey carried out by the staff during patrolling. In addition, data on encounter rate is also being collected as part of *All India Tiger Monitoring Program and camera trapping exercise*. The data collected from survey blocks ranging in size from 10 to 25 km^2 as part of 'Monitoring of Tigers, Co-predators, Prey and their Habitat' was used to assess the presence absence of tiger and co-predators. The total of 59 such blocks were used for collecting the

information and the data collected was analyzed to find out the density distribution of tigers and elephants. And these data were used to find the wildlife exposure in High-risk zones.

Modelling: The Max Ent software (version 3.3.3.e; http://www.cs.princeton.edu/schapire/maxent/) was utilized for fire modelling, generating probability distribution maps based on similar situations across terrain using maximum entropy techniques and considering GPS coordinates (Elith et al 2011). Even with limited presence records, Maxent predicts species' ecological niches effectively. This study aimed to develop a fire prediction model based on Max Ent's principles, which minimize relative entropy between presence-only instances and background landscape data. Unlike traditional approaches like logistic regression or random forest, Max Ent utilizes presence-background data to predict forest fires, reducing assumptions and sample selection bias risks. Recent software versions incorporate transformation methods to standardize features and prevent overfitting. Max Ent is particularly suitable for forest fire investigations due to its reliance on presence-only data (Arnold et al 2014, Phillips and Elith 2013).

Parameter settings: Initially, all feature maps were projected from the GCS-WGS-1984 geographic projection system to the WGS-1984-UTM-Zone-43 N plane projection system, which is adequate for the research area. The polyline vector maps of the power line, water bodies network, and point vector map of human habitations were then used to create Euclidean distance raster maps. These raster maps were created to determine the distance between seismic occurrences and power lines, water bodies, and human settlements. The DEM was used to create topographic feature maps of Elevation, Slope, Aspect, Accumulation, TRI, Plan curvature, Profile Curvature, TPI, TWI, SPI, LS factor. This work employed raster maps of averaged NDVI and forest cover to train the algorithm.

Following that, all feature maps were re sampled to the

Table 3. Power lines in PTR

Division	Range	Section	Name of the power line project	Length (km) approx.	Width (m)	Area (sq.km)
PTR-East	Thekkady	Edapalayam	Moozhiyar-Theni- 110 KV	5.2	15	0.078
PTR-East	Vallakkadavu	Thondiyar	Thondiyar - Manamuttymala 220 KV	6	25	0.15
PTR-East	Vallakkadavu	Vallakkadavu	Moozhiyar - Vandiperiyar - 110 KV	9.2	30	0.276
PTR-East	Vallakkadavu	Vallakkadavu And kozhikanam, Kalaradichan	Vallakkadavu-Pachakanam Estate-11 KV	8	25	0.2

same spatial extent and 10 metre cell size as the NDVI raster. Following that, the feature maps were normalized so that their pixel values were in the range of 0 to 1 (Chang 2017). This is a standard machine learning approach for reducing calculation time. All of these geo processing techniques were carried out in the Arc GIS environment. Because the normalized maps are easily readable by Max Ent, they were exported in ASCII format. Comma-Separated Values (CSV) file was also created from the presence-only dataset of forest hazard events. Max Ent is a java program-based package that was employed in this investigation. All of the feature maps were stacked with matching extents during the creation of the prediction map, and feature attributes were retrieved from the feature stack using the presence-only datasets re event coordinates. The presence-only dataset was thus data trimmed, resulting in a more credible dataset. The dataset was split into two parts: 25% was utilized for testing, while the rest was used to train Max Ent. For cross validation, the training dataset was also partitioned into ve-folds. Following that, a background dataset was created by picking 1000 random points from the research area's perimeter. There is a maximum of 5,000 backdrop points, and linear, quadratic, and hinge features were utilized (Phillips and Dudik 2008). For model creation (Flory et al 2012), 100 repetitions were preserved, and the occurrence sites were randomly partitioned into two sub samples, with 75 percent of the locations used as the training dataset and the remaining 25% used to test the resulting (partitioned) models. The model's accuracy was measured using the area under the curve (AUC) of a receiver operating characteristic (ROC) plot (ranging from 0.5 = random to 1 = perfect discrimination). The Jack knife method was used to determine the factors' importance (Yang et al 2013). A probability map of various risks was created using an average of 100 model projections. The model parameters and values, on the other hand, were left at their default levels. Additionally, all values between 0.6 and 0.8 as high-risk zones, and those between 0.2 and 0.6 as Medium Risk zones, values below 0.2 were determined as low risk zones.

RESULTS AND DISCUSSION

Forest fire risk mapping: Fifty six fire incidences were found to be Spatio-temporally independent. Jack knife test results showed that based on the percentage contribution, "Distance to settlement " (17 %), "Temperature" (temp) (16.7%), "distance to water body" (d2w) (16.3 %) and "Forest cover" (10.6%) were the highest contributors. Based on permutation importance, "Precipitation of seasonality" (bio15) was the most significant variable (16.6%) followed by "Temperature" (temp) (29.8%) (Table 4). The area under the

curve (AUC) score was 0.955 for the training data from our model, which indicates moderate to excellent predictive ability of the model (Fig. 5). The classified fire prediction map showed good discrimination between high, medium and low fire risk categories. The result demonstrated that out of the total geographical area of Periyar tiger reserve 96 sq.km area (10.3%) was under high-risk category, 1.5 ha area (0.001%) under medium risk and 803 sq.km area (86.8%) under low-risk category (Fig. 6). The areas near to village having moderate canopy density were highly affected by fire.
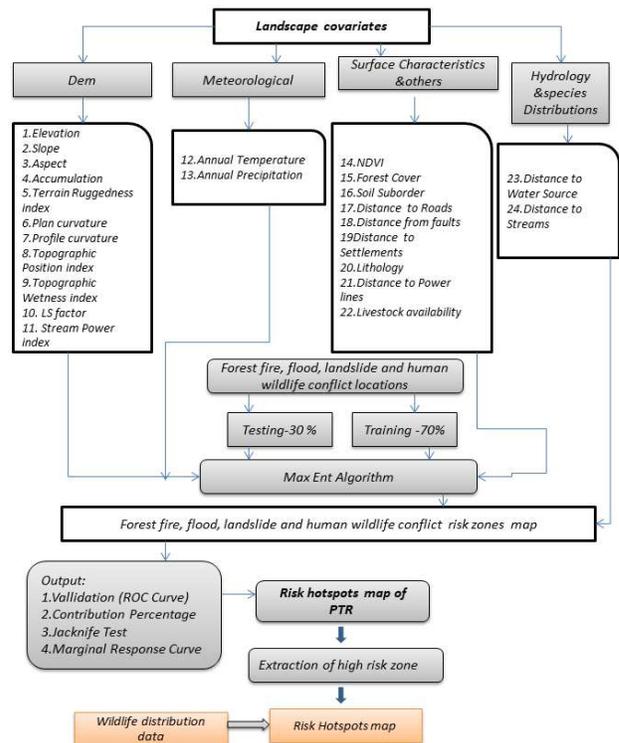
Fig. 4. Methodology
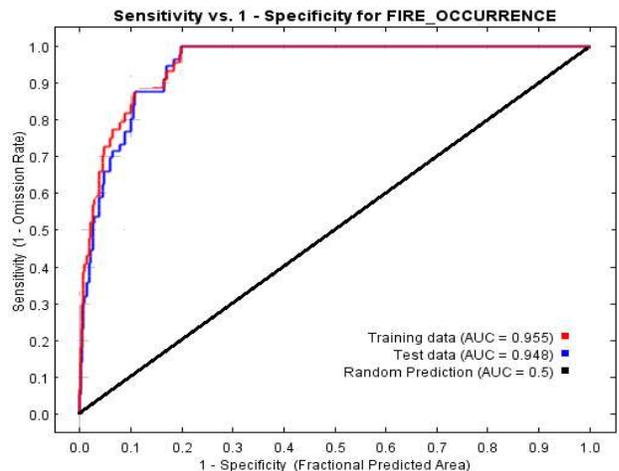
Fig. 5. Area under curve of fire (AUC)

Flood risk zone mapping: Twenty flood incidences were spatio-temporally independent. Jack knife test results showed that based on the percentage contribution, "Distance to stream " (32.8 %), "Temperature" (temp) (24 %), "Digital Elevation model" (Dem) (10.3 %) and "Rainfall" (9.3 %) were the highest contributors. Based on permutation importance, "distance to stream" (stream) was the most significant variable (37.6 %) followed by "Temperature" (temp) (14 %) (Table 5). The area under the curve (AUC) score was 0.979 for the training data from our model, which indicates moderate to excellent predictive ability of the model (Fig. 7).

Landslide risk zone mapping: Nine landslide incidences were found to be spatio-temporally independent. Jack knife test results showed that based on the percentage contribution, "soil " (51.5 %), "topographic roughness index " (tri) (28.8 %), "Forest cover" (fc) (12.2 %) and "NDVI (4.9 %) were the highest contributors. Based on permutation importance, "soil" (stream) was the most significant variable (39.7 %) followed by "Topographic roughness index" (tri) (31.1 %) (Table 6). The area under the curve (AUC) score

was 0.923 for the training data from our model, which indicates moderate to excellent predictive ability of the model (Fig. 9). The classified flood prediction map showed good discrimination between high, medium and low flood risk categories. The result demonstrated that out of the total geographical area of Periyar tiger reserve 48 sq.km area (5.1%) was under high-risk category, 148 sq.km area (16 %) under medium risk and 703 sq.km area (76 %) under low-risk category (Fig. 8). The areas near to waterfalls were highly affected by flood. The classified landslide prediction map showed good discrimination between high, medium and low flood risk categories. The result demonstrated that out of the total geographical area of Periyar tiger reserve 290 sq.km area (31 %) was under high-risk category, 388.75 sq.km area (42%) under medium risk and 220 sq.km area (23 %) under low-risk category (Fig. 10). The areas near to streams having were highly affected by landslide.

Human wildlife conflict zone mapping: Seventeen conflict incidences were found to be spatio-temporally independent. Jackknife test results showed that based on the percentage

Table 4. Percent contribution and permutation importance of variables (Fire)

Variable	Code	Percent contribution (%)	Permutation importance (%)
Live stock availability	livestock	17	7.4
Temperature	temp	16.7	29.8
Distance to waterbody	d2w	16.3	6
Forest cover	fc	10.6	0.4
Distance to road	ro	9.7	0
Rainfall	rainfall	7.1	12.2
Soil Suborder	soil	5.7	2.5
Digital elevation model	dem	3.9	23.3
Normalized difference vegetation index	ndvi	3	4.6
Distance to powerline	power	2	4.9
Flow accumulation	fa	1.9	2.2
Aspect	asp	1.6	3.1
Lithology	litho	1.3	0
Distance to streams	stream	0.7	0.4
Distance to faults	fault	0.7	0.7
Terrain ruggedness index	tri	0.6	1.9
Topographic position index	tpi	0.4	0.1
Stream power index	spi	0.2	0
Plan curvature	plan	0.2	0.3
Slope	slope	0.2	0
Profile curvature	profile	0.1	0.1
Distance to Settlements	ts	0.1	0.2
LS Factor	lsfactor	0	0
Topographic wetness index	twi	0	0
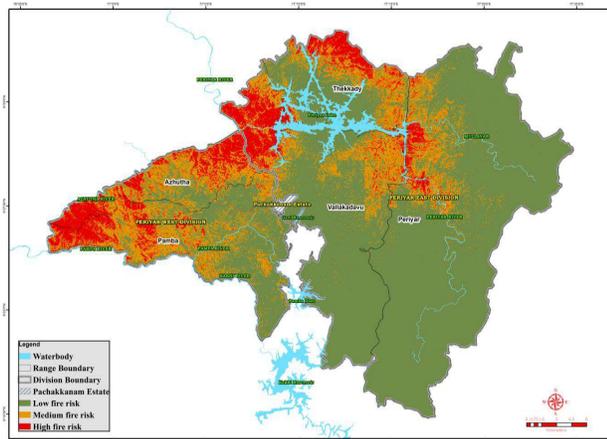
Fig. 6. Classified fire risk map

contribution, "distance from road "(ro) (30.1 %), "Livestock " (19.3 %), "Forest cover" (fc) (17.3 %) and "Distance to waterbody (d2w) (7.7 %) were the highest contributors. Based on permutation importance, "distance to road" (ro) was the most significant variable (42.5 %) followed by "livestock" (21.4 %) (Table 7). The area under the curve (AUC) score was 0.986 for the training data from our model, which indicates moderate to excellent predictive ability of the

Fig. 9. Area under Curve of landslide (AUC)

Fig. 7. Area under Curve of Flood (AUC)
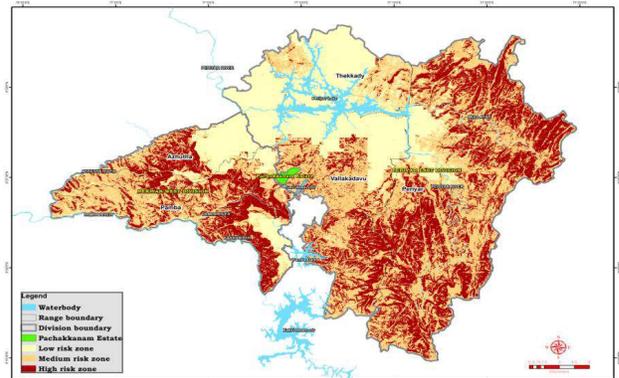
Fig. 10. Classified landslide risk map
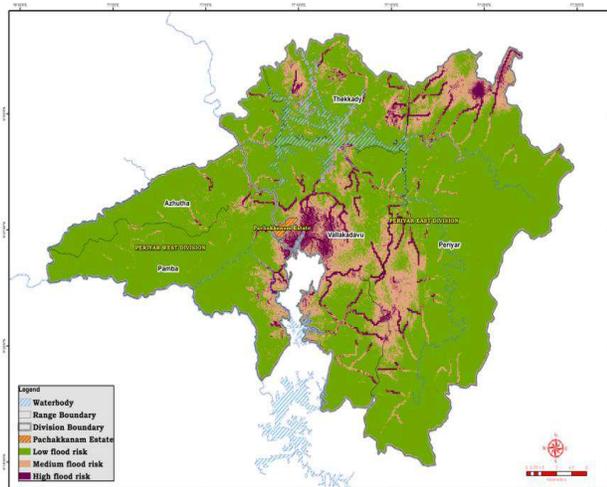
Fig. 8. Classified flood risk map
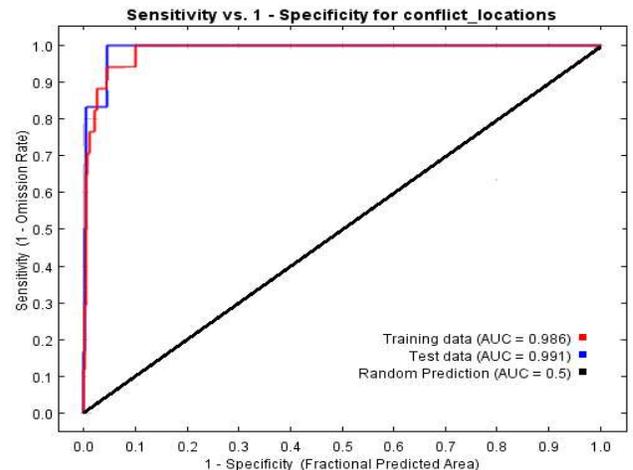
Fig. 11. Area under Curve of HWC (AUC)

model (Fig. 11). The classified human wildlife conflict prediction map showed good discrimination between high, medium and low human wildlife conflict risk categories. The result demonstrated that out of the total geographical area of Periyar tiger reserve 81 sq.km area (8.7 %) was under high-risk category, 103.51 sq.km area (11.11%) under medium risk and 714 sq.km area (77 %) under low-risk category (Fig.

12). The areas near to fringe villages having moderate canopy density were highly affected by human wildlife conflict.

Risk hotspots map prepared using high risk zones of forest fire, flood, landslide and human wildlife conflict. It demonstrated that 55 % of the area is subjected to risks (Fig. 13), reaching a proportion of landslides up to 31%, human
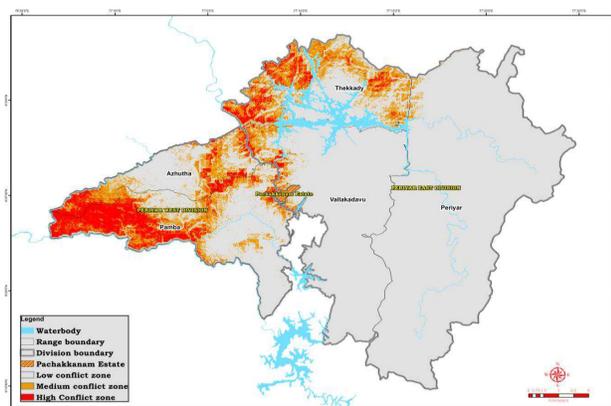
Fig. 12. Classified human wildlife conflict risk zone map
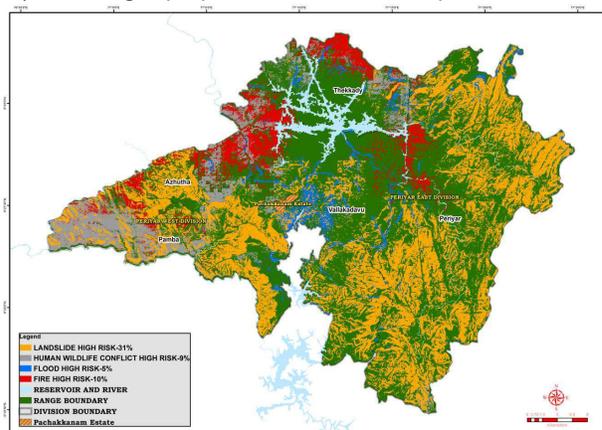
Fig. 13. Risk hotspot map of Periyar Tiger Reserve

Table 5. Percent contribution and permutation importance of variables (Flood)

Variable	Code	Percent contribution (%)	Permutation importance (%)
Distance to streams	stream	32.8	37.6
Temperature	temp	24	14
Digital elevation model	dem	10.3	23.6
Rainfall	rainfall	9.3	8.5
Live stock availability	livestock	7.1	3.4
Distance to faults	fault	5.2	6.1
Distance to waterbody	d2w	3	0
Forest cover	fc	2	1.5
Soil suborder	soil	1.5	0
LS factor	lsfactor	1	2.2
Normalized difference vegetation index	ndvi	0.9	1.2
Topographic wetness index	twi	0.8	0.1
Aspect	asp	0.8	1
Distance to road	ro	0.5	0.6
Plan curvature	plan	0.3	0
Slope	slope	0.3	0
Distance to settlements	ts	0.1	0.1
Flow accumulation	fa	0	0.1
Terrain ruggedness index	tri	0	0
Profile curvature	profile	0	0
Lithology	litho	0	0
Stream power index	spi	0	0
Topographic position index	tpi	0	0
Distance to powerline	power	0	0
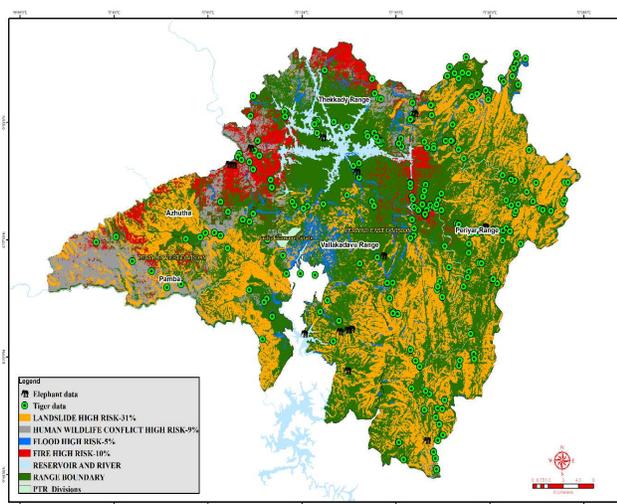
Fig. 14. Wildlife risk exposure map

Table 7. Percent contribution and permutation importance of variables (HWC)

Variable	Code	Percent contribution (%)	Permutation importance (%)
Distance to road	ro	30.1	42.5
Live stock availability	livestock	19.3	21.4
Forest cover	fc	17.3	1.3
Distance to waterbody	d2w	7.7	0.1
Soil suborder	soil	6.2	7.9
Distance to settlements	ts	4	0.1
Distance to streams	stream	3.1	18.8
Normalized difference vegetation index	ndvi	2.6	1.1
Distance to powerline	power	2.4	0
Lithology	litho	1.8	0
Aspect	asp	1.5	0.4
Plan curvature	plan	1.2	1.6
Flow accumulation	fa	1.1	2
Slope	slope	0.9	0
Terrain ruggedness index	tri	0.4	0.2
Distance to faults	fault	0.3	1.5
Temperature	temp	0.1	0.8
Digital elevation model	dem	0	0
LS factor	lsfactor	0	0.3
Profile curvature	profile	0	0.1
Rainfall	rainfall	0	0
Stream power index	spi	0	0
Topographic position index	tpi	0	0
Topographic wetness index	twi	0	0

Table 6. Percent contribution and permutation importance of variables (Landslide)

Variable	Code	Percent contribution (%)	Permutation importance (%)
Soil suborder	soil	51.5	39.7
Terrain ruggedness index	tri	28.8	31.1
Forest cover	fc	12.2	1.5
Normalized difference vegetation index	ndvi	4.9	6.3
Distance to streams	stream	1.9	19.4
Stream power index	spi	0.5	2
Flow accumulation	fa	0.1	0
LS Factor	lsfactor	0	0
Distance to powerline	power	0	0
Plan curvature	plan	0	0
Live stock availability	livestock	0	0
Lithology	litho	0	0
Distance to faults	fault	0	0
Topographic wetness index	twi	0	0
Distance to settlements	ts	0	0
Topographic position index	tpi	0	0
Temperature	temp	0	0
Slope	slope	0	0
Distance to road	ro	0	0
Rainfall	rainfall	0	0
Profile curvature	profile	0	0
Digital elevation model	dem	0	0
Distance to waterbody	d2w	0	0
Aspect	asp	0	0

wildlife conflict up to 9%, flood up to 5% and fire up to 10 % in the whole territory.

Exposure of wildlife population: The human settlements in the Periyar Tiger Reserve are disproportionately concentrated in areas of high risk. In contrast, low-risk areas are disproportionately unpopulated. Nearly half of Tiger population in the region lives in areas that are highly susceptible to landslide. Few percentages of elephant population live in areas that are highly suspectable to Human wildlife Conflict zones. Fire and flood risk areas suspectable to the wildlife is comparatively less. This area comprises only 55 % of the study region, but is home to 50% of its population (Fig. 14).

CONCLUSIONS

Analyzing climate change-related risk events is crucial for protecting forests from further degradation in India. Research

is urgently needed in risk detection, suppression, and risk ecology to better manage forest risks. This study evaluates long-term forest fire, flood, landslide, and human-wildlife conflict events across India's state boundaries, seasonal trends, land use and land cover categories, and future climate anomalies. The methodology used here is more advanced than previous frequency analysis methods, offering improved accuracy in risk prediction. GIS-based modelling helps identify, map, and quantify biophysical characteristics and predict future risks. The developed risk model is vital for identifying and controlling risks in Western Ghats protected areas, aiming to reduce hazard events and losses. The 55% of the area is at risk, with landslides affecting 31%, human-wildlife conflict 9%, flood 5%, and fire 10%. Human settlements in the Periyar Tiger Reserve are concentrated in high-risk areas, while low-risk areas are less populated. The significant portion of the tiger population resides in landslide-prone areas, while a smaller percentage of the elephant population faces high human-wildlife conflict risk. This multi-hazard map can assist local administrators in identifying large-scale hazard-prone areas effectively.

ACKNOWLEDGEMENT

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Gender Roles in Agroforestry Systems of Ayodhya district, Uttar Pradesh

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Abstract: This study was conducted in all the eleven blocks of Ayodhya district of Uttar Pradesh for a period of two years using questionnaire surveys to study the gender roles in agroforestry systems and tree management, preferences of tree species, access to resources and participation in decision-making, gendered rights to harvesting and processing of agroforestry tree products, marketing of products, spaces and ownership of trees and identified the factors hindering gender adoption of agroforestry and evaluated its implications for agroforestry interventions. The males were involved in majority of the agroforestry activities such as ploughing, tree planting, fertilization, pruning, harvesting, transport and sales. Males had greater access to land ownership, land transfer rights, loan and irrigation facilities. The decision on planting of species, which area to plant, how many numbers of plants to be planted, irrigation, pruning, harvesting and sale was mostly taken by males whereas the females took decision on the season of planting, financial management, fertilizer application and processing. Males enjoyed the rights of harvesting, marketing and tree ownership and the females had the right of processing agroforestry products. Females preferred fruit bearing trees whereas the men preferred timber-yielding trees. Family opposition and limited cash availability was seen as a hindrance by the females in adoption of agroforestry systems and they stressed on policy interventions to improve the adoption rate of agroforestry systems. The societal pressure restricts the females from becoming financial independent and decision makers. High level policy intervention and changes in social behaviour and attitudes is required to cherish the dream of women empowerment in this region.

Keywords: Agroforestry adoption, Decision-making, Gendered-rights, Implications, Tree preferences

Over the years the attention paid by scientific community to gender and its role in development and inequalities between men and women has increased (Kiptot et al 2014). If these gender imbalances are addressed, it will increase food security and prosperity. Gender inequalities are determined by the factors such as social norms, institutional rules, gendered division of labour, gendered knowledge systems, gendered differences in access to natural, physical, financial and human capital and gendered differences in decision-making processes (Empacher et al 2001, Ott 2002). Social norms shape the gender decisions and choice. Women are always looked upon as weaker section of the society as compared to their male counterparts. To address the gender imbalances prevalent in the society, it is important to understand the social relations between men and women. Gender roles are defined as the socially accepted tasks and responsibilities that are assigned to men and women (Manfre and Rubin 2012). These gender roles may change with time, within households and caste. Traditionally, women play a lesser role than men in the decision-making process that affect and control their own lives and those of their homesteads and entitlements. Gender division of labor is itself rooted in religious and other cultural belief systems in which concepts of masculinity and femininity, and norms about behavior that is appropriate for each sex, are intrinsic. So, depending on their roles and responsibilities, the choices and preferences of men and women differ with respect to tree species and agroforestry system choices.

Gender participation in agroforestry, varies according to preferences and values of tree species and products, as well as to the level of complexity of practices (Ratnapuri 2011). In Africa, women's participation is low in agroforestry enterprises that are considered men's domains such as timber and high in enterprises that have little or no commercial value, such as collection of indigenous fruits and vegetables; and women are often confined to the lower end of the value chain of agroforestry products (retailing), which limits their control over and returns from the productive process (Kiptot and Franzel 2012). For women's income, agroforestry value chains are particularly important, but low access to capital, technology and information, constrain women from developing their enterprises further. Furthermore, tree species preferences in agroforestry also vary between male and female household members. The study in Pakistan highlighted that men were keen on *Eucalyptus* species, as it had better survival rates, whereas

women preferred *Dalbergia sissoo, Melia azedarach* and *Morus alba,* which could provide better income (Muhammad 2003).

As gender roles are dynamic and depend upon time, circumstances demand and requirements, it is important to understand the complexity of gender roles and social norms. If this is not understood, it will not be possible to improve agroforestry research and development. Once this gap is filled there will be better information on constraints faced by gender in adoption of agroforestry systems, value addition of products which can then be taken up for further research and development. This paper studied the gender-wise roles, preferences, rights, participation in decision-making and factors hindering adoption of agroforestry systems.

MATERIAL AND METHODS

Study site: This study was conducted in the Ayodhya district of Uttar Pradesh which consists of five tehsils and eleven blocks. This district lies between 26.7730 $^{\circ}$N and 82.1458 $^{\circ}$E. This district is situated 93 m above MSL (Mean Sea Level). The climate of the district is tropical monsoon. The average temperature varies from 32 $^{\circ}$C in summers to 16 $^{\circ}$C in winters and the average annual rainfall is 1067 mm. The study area includes reserve forests, remnant vegetation patches, rivers, temple ponds, wetlands, gardens, agroforestry systems, paddy fields and human habitations.

Method: Questionnaire surveys were conducted for two years (2021 to 2023) to understand gender roles, decision-making, constraints and interventions required in agroforestry systems practiced in Ayodhya district of Uttar Pradesh which consists of eleven blocks. From each block, 10 villages were identified and from each village 10 households were selected. In totality, 1100 households in 11 blocks were surveyed in which 77 households were found to have five agroforestry systems namely agri-silviculture system, agri-horticulture system, silvipastoral system and aquasilviculture system. Questions related to gender roles in agroforestry systems and tree management, gendered preferences on tree species, access to resources and participation in decision-making, gendered rights to harvesting and processing of agroforestry tree products, marketing of products, spaces and ownership of trees, factors hindering gender adoption of agroforestry and its implications for agroforestry interventions were considered. To find out the most preferred tree species as per house owner's opinion, Ahire and Kumar (2006) method was followed. The owners were asked to give a score (from 1-10) to each tree species that the owner's listed as preferred species. The most preferred species was given the highest score and the rest of the tree species were given the scores in descending order of preferences. The tree species having the highest score was given 1st rank and so on in ascending order. Chi-square test was used for analyses using SPSS (version 19.0).

RESULTS AND DISCUSSION

Gender roles in agroforestry systems and tree management: Nine major farming activities were in Ayodhya district namely ploughing, pit digging, tree planting, fertilization, watering, pruning, harvesting, transport and sale (Table 1). In all the eleven blocks, ploughing, tree planting, fertilization, pruning, harvesting, transport, sales activity was performed mainly by males and the least by females (Table 1). Across all the blocks, there was no statistically significant difference for ploughing, tree planting, pruning and harvesting and there was statistically significant difference for fertilization application. According to the studies conducted by other researchers males had major responsibility in ploughing and transportation activities (Catacutan and Naz 2015), tree planting activity (Phiri et al 2004), fertilization and sale activities (Birhanu and Guye 2022), which is similar to present study but dissimilar to the study conducted by Birhanu and Guye (2022) wherein 92.5% of males in four Southern Ethiopia villages were involved in pruning. Across all the blocks, the pit digging and irrigation activity was performed by both genders, and least by males. There was no statistically significant difference across the blocks for pit digging and irrigation activity. Birhanu and Guye (2022) observed that males shared the major responsibility in irrigation activity. The females preferred species such as *Azadirachta indica, Prosopis cineraria, Tectona grandis, Psidium guajava, Dalbergia sissoo* and *Mangifera indica* whereas the males preferred species such as *Eucalyptus globulus, Madhuca indica, Mangifera indica* and *Azadirachta indica* (Table 2).

Gender-wise access to resources: There was access to eight major farming resources in Ayodhya district namely land ownership, transfer rights, loans, trainings, seeds, irrigation facilities, market and harvest (Table 3). The males had the highest access to land ownership followed by females and both genders and there was no statistically significant difference across the blocks for land ownership. In all the eleven blocks, the highest access to land transfer rights, loan and irrigation facilities was enjoyed by males, and least by females. There was statistically significant difference across the blocks for access to land transfer rights and irrigation facilities but access to loan was not statistically significantly different across the blocks. Catacutan and Naz (2015) in Vietnam, observed that males had higher access to loans as compared to females which is similar to present

Table 1. Gender roles in agroforestry and tree management of selected agroforestry systems in Ayodhya district, Uttar Pradesh.

Activities	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Ploughing	Male	79.22	100.00	66.67	85.7	75.00	71.43	83.33	100.00	66.67	62.50	75.00	66.67	0.66
	Female	2.60	0.00	16.67	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.11	
	Both	18.18	0.00	16.67	14.3	25.00	28.57	16.67	0.00	33.33	37.50	25.00	22.22	
Pit digging	Male	22.08	33.33	33.33	42.9	50.00	71.43	50.00	100.00	66.67	62.50	62.50	66.67	0.39
	Female	33.77	33.33	16.67	0.0	25.00	0.00	16.67	0.00	0.00	0.00	0.00	11.11	
	Both	44.16	33.33	50.00	57.1	25.00	28.57	33.33	0.00	33.33	37.50	37.50	22.22	
Tree planting	Male	57.14	50.00	50.00	28.6	25.00	0.00	16.67	14.29	33.33	0.00	0.00	22.22	0.59
	Female	10.39	8.33	16.67	28.6	25.00	42.86	50.00	42.86	33.33	50.00	50.00	33.33	
	Both	32.47	41.67	33.33	42.9	50.00	57.14	33.33	42.86	33.33	50.00	50.00	44.44	
Fertilization	Male	45.45	75.00	33.33	57.1	50.00	71.43	50.00	100.00	33.33	0.00	0.00	22.22	0.02
	Female	20.78	8.33	16.67	0.0	25.00	0.00	16.67	0.00	33.33	50.00	50.00	33.33	
	Both	33.77	16.67	50.00	42.9	25.00	28.57	33.33	0.00	33.33	50.00	50.00	44.44	
Irrigation	Male	25.97	16.67	16.67	28.6	0.00	28.57	16.67	28.57	33.33	37.50	37.50	33.33	0.99
	Female	35.06	41.67	33.33	28.6	50.00	28.57	33.33	28.57	33.33	37.50	37.50	33.33	
	Both	38.96	41.67	50.00	42.9	50.00	42.86	50.00	42.86	33.33	25.00	25.00	33.33	
Pruning	Male	77.92	75.00	66.67	85.7	75.00	71.43	66.67	71.43	66.67	87.50	87.50	88.89	0.96
	Female	5.19	8.33	16.67	0.0	0.00	0.00	16.67	0.00	0.00	0.00	0.00	11.11	
	Both	16.88	16.67	16.67	14.3	25.00	28.57	16.67	28.57	33.33	12.50	12.50	0.00	
Harvesting	Male	76.62	83.33	66.67	57.1	75.00	85.71	66.67	85.71	100.00	87.50	75.00	66.67	0.93
	Female	2.60	0.00	0.00	14.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.11	
	Both	20.78	16.67	33.33	28.6	25.00	14.29	33.33	14.29	0.00	12.50	25.00	22.22	
Transport	Male	97.40	100.00	83.33	100.0	100.00	100.00	83.33	100.00	100.00	100.00	100.00	100.00	
	Female	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Both	2.60	0.00	16.67	0.0	0.00	0.00	16.67	0.00	0.00	0.00	0.00	0.00	
Sale	Male	77.92	75.00	66.67	71.4	50.00	85.71	66.67	71.43	100.00	87.50	100.00	77.78	
	Female	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Both	22.08	25.00	33.33	28.6	50.00	14.29	33.33	28.57	0.00	12.50	0.00	22.22	

The level of significance is (p < 0.05)

study. In all the blocks, both the genders had the highest access to training, seeds, market, and least by females. There was statistically significant difference across the blocks for access to training, seeds and access to market. In earlier observations females had higher access to seeds (Catacutan and Naz 2015) and market (Birhanu and Guye 2022) whereas in the present study, both the genders had higher access to seeds as well as market. Across all the blocks, access to harvest was highest by both gender and least by males. There was no statistically significant difference across the blocks for access to harvest. Birhanu and Guye (2022) observed that females had higher access to harvest.

Gender-wise participation in decision-making, harvesting and processing of agroforestry tree products: Across all the eleven blocks, the decision on planting of species, numbers of plants to be planted, irrigation, pruning, harvesting and sale was mostly taken by males and least by both gender (Table 4). There was no statistically significant difference across the blocks for decision related to planting of species, numbers of plants to be planted, irrigation, pruning and sale whereas there was statistically significant difference across the blocks for decision making on harvesting. Birhanu and Guye (2022) observed that decision on planting of species was taken by females which contradicted the present study, where the males took decision on planting of species. Catacutan and Naz (2015) concluded that decision on numbers of plants to plant, irrigation and sale were taken by males. The decision on which area to plant there was taken mainly by males and least by females and there was no statistically significant difference across the block for the decision on the area to

plant. Across all blocks, the decision on season of planting, financial management, fertilizer application and processing were mostly taken by females and least by both the genders. There was no statistically significant difference across the blocks for decision on season of planting, financial management, fertilizer application and processing. Catacutan and Naz (2015) in Vietnam mentioned that decision on financial management are taken by males. Across all blocks, majority of the males enjoyed the rights of harvesting, marketing, tree ownership and least by both genders. There was statistically significant difference across the blocks for rights to harvesting but this was not the case for rights to market and tree ownership. Across all the blocks, the right of processing was mostly enjoyed by females and least by both gender and there was no statistically significant difference across the blocks**.**

Factors hindering gender adoption of agroforestry and its implications for agroforestry interventions: The lack of transportation, limited business and negotiation skills, high initial investment and lack of extension activity was seen as a hindrance, the highest by males and least by females (Table 6). But lack of transportation, high initial investment and lack of extension activities viewed as a hinderance in agroforestry system was not statistically significantly different across the blocks. Catacutan and Naz (2015) found that high initial investment was seen as a major hindrance by males. The family opposition across all the blocks was seen as hindrance, the highest by females and least by males. Across all blocks, limited products, poor understanding of tree management, limited land availability, absence of a guiding policy on agroforestry were seen as hindrance, the highest by both gender and least by females. There was no statistically

Table 2. Gendered ranking of species showing tree preferences in selected agroforestry systems in Ayodhya district, Uttar Pradesh

Name of tree species	Milkipur		Sohawal		Harringtonganj		Mawai		Rudauli		Mayabazar		Bikapur		Masodha		Purabazar		Amaniganj		Tarun	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Eucalyptus spp.	1	10	3	10	2	4	1	3	8	10	4	2	1	6	5	7	3	8	1	10	8	10
Tectona grandis	2	5	1	3	1	5	2	8	10	3	5	1	9	5	10	4	8	1	2	5	10	3
Swietenia spp.	4	8	10	5	10	2	4	5	5	5	8	10	4	8	8	2	9	10	4	8	5	5
Ailanthus excelsa	3	6	8	4	6	8	3	2	7	4	6	7	3	4	7	6	7	6	3	6	7	2
Dalbergia sissoo	5	4	2	8	7	7	5	4	4	8	7	4	5	7	4	5	4	7	5	1	4	8
Mangifera indica	6	1	6	10	5	3	6	6	6	2	1	5	6	3	6	3	6	5	6	3	6	1
Prosopis cineraria	7	7	2	2	8	10	7	9	3	1	10	8	7	2	3	10	5	2	7	4	3	4
Madhuca indica	8	9	4	7	9	6	8	7	1	7	2	9	8	10	1	8	2	9	8	2	1	7
Azadirachta indica	9	2	5	9	4	9	9	1	2	9	9	6	2	9	2	9	1	4	9	9	2	9
Psidium gujava	10	3	7	6	3	1	10	10	9	6	3	3	10	1	9	1	10	3	10	7	9	6

Table 3. Gender-wise access to resources of farmers of selected agroforestry systems in Ayodhya district, Uttar Pradesh

Activities	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Land ownership	Male	71.43	83.33	66.67	57.14	100.00	85.71	50.00	85.71	33.33	50.00	75.00	77.78	0.91
	Female	14.29	8.33	16.67	14.29	0.00	14.29	16.67	14.29	33.33	25.00	12.50	11.11	
	Both	14.29	8.33	16.67	28.57	0.00	0.00	33.33	0.00	33.33	25.00	12.50	11.11	
Land transfer rights	Male	49.35	41.67	50.00	85.71	75.00	85.71	66.67	14.29	0.00	50.00	12.50	55.56	0.02
	Female	18.18	41.67	33.33	14.29	0.00	14.29	0.00	14.29	0.00	25.00	12.50	11.11	
	Both	32.47	16.67	16.67	0.00	25.00	0.00	33.33	71.43	100.00	25.00	75.00	33.33	
Loans	Male	54.55	66.67	33.33	85.71	75.00	28.57	33.33	42.86	66.67	50.00	62.50	55.56	0.59
	Female	18.18	16.67	16.67	0.00	0.00	14.29	50.00	14.29	0.00	37.50	12.50	22.22	
	Both	27.27	16.67	50.00	14.29	25.00	57.14	16.67	42.86	33.33	12.50	25.00	22.22	
Trainings	Male	37.66	50.00	16.67	85.71	75.00	28.57	0.00	42.86	33.33	37.50	12.50	33.33	0.01
	Female	23.38	33.33	0.00	14.29	0.00	57.14	0.00	42.86	0.00	37.50	12.50	22.22	
	Both	38.96	16.67	83.33	0.00	25.00	14.29	100.00	14.29	66.67	25.00	75.00	44.44	
Seeds	Male	38.96	41.67	0.00	85.71	0.00	14.29	0.00	85.71	33.33	62.50	50.00	22.22	0.00
	Female	18.18	16.67	0.00	0.00	0.00	14.29	0.00	0.00	0.00	37.50	37.50	55.56	
	Both	42.86	41.67	100.00	14.29	100.00	71.43	100.00	14.29	66.67	37.50	12.50	22.22	
Irrigation facilities	Male	48.05	58.33	16.67	0.00	25.00	28.57	50.00	71.43	33.33	62.50	87.50	55.56	0.01
	Female	23.38	16.67	0.00	85.71	25.00	42.86	16.67	0.00	33.33	12.50	12.50	22.22	
	Both	28.57	25.00	83.33	14.29	50.00	28.57	33.33	28.57	33.33	25.00	0.00	22.22	
Market	Male	38.96	33.33	0.00	85.71	25.00	85.71	50.00	71.43	66.67	12.50	0.00	22.22	0.01
	Female	3.90	8.33	0.00	0.00	25.00	0.00	16.67	0.00	0.00	0.00	0.00	0.00	
	Both	57.14	58.33	100.00	14.29	50.00	14.29	33.33	28.57	33.33	87.50	100.00	77.78	
Harvest	Male	20.78	25.00	16.67	0.00	50.00	0.00	33.33	14.29	0.00	37.50	12.50	33.33	0.07
	Female	27.27	16.67	50.00	0.00	0.00	0.00	33.33	28.57	33.33	50.00	62.50	22.22	
	Both	51.95	58.33	33.33	100.00	50.00	100.00	50.00	42.86	66.67	12.50	25.00	44.44	

The level of significance is (p < 0.05)

Table 4. Gender-wise decision making in farming activities of selected agroforestry systems in Ayodhya district, Uttar Pradesh

Activities	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Planting of species	Male	53.25	50.00	33.33	71.43	50.00	57.14	50.00	42.86	66.67	62.50	62.50	44.44	0.98
	Female	33.77	33.33	50.00	28.57	50.00	42.86	33.33	28.57	33.33	25.00	12.50	44.44	
	Both	12.99	16.67	16.67	0.00	0.00	0.00	16.67	28.57	0.00	12.50	25.00	11.11	
Which area to plant	Male	49.35	41.67	66.67	71.43	50.00	71.43	50.00	57.14	33.33	37.50	37.50	33.33	0.98
	Female	31.17	33.33	16.67	14.29	50.00	14.29	33.33	28.57	66.67	37.50	37.50	33.33	
	Both	20.78	25.00	16.67	14.29	0.00	14.29	16.67	28.57	0.00	25.00	25.00	33.33	
How many numbers to plant	Male	71.43	75.00	66.67	42.86	50.00	71.43	50.00	71.43	66.67	87.50	75.00	100.00	0.92
	Female	16.88	16.67	16.67	28.57	25.00	14.29	33.33	14.29	33.33	12.50	12.50	0.00	
	Both	11.69	8.33	16.67	28.57	25.00	14.29	16.67	14.29	0.00	0.00	12.50	0.00	
Season of planting	Male	33.77	33.33	66.67	42.86	50.00	42.86	33.33	42.86	0.00	12.50	25.00	22.22	0.83
	Female	49.35	50.00	16.67	28.57	25.00	28.57	50.00	42.86	100.00	75.00	62.50	66.67	
	Both	16.88	16.67	16.67	28.57	25.00	28.57	16.67	14.29	0.00	12.50	12.50	11.11	
Financial management	Male	66.23	50.00	66.67	85.71	50.00	57.14	83.33	71.43	100.00	75.00	62.50	55.56	0.89
	Female	24.68	41.67	33.33	14.29	25.00	42.86	16.67	14.29	0.00	12.50	25.00	22.22	
	Both	9.09	8.33	0.00	0.00	25.00	0.00	0.00	14.29	0.00	12.50	12.50	22.22	
Fertilizer application	Male	38.96	33.33	66.67	14.29	75.00	42.86	33.33	42.86	33.33	25.00	50.00	33.33	0.88
	Female	48.05	41.67	33.33	71.43	25.00	28.57	50.00	57.14	66.67	62.50	37.50	55.56	
	Both	12.99	25.00	0.00	14.29	0.00	28.57	16.67	0.00	0.00	12.50	12.50	11.11	
Irrigation	Male	50.65	58.33	50.00	42.86	50.00	28.57	66.67	57.14	66.67	75.00	75.00	0.00	0.12
	Female	35.06	25.00	50.00	28.57	25.00	42.86	16.67	28.57	33.33	12.50	12.50	100.00	
	Both	14.29	16.67	0.00	28.57	25.00	28.57	16.67	14.29	0.00	12.50	12.50	0.00	
Pruning	Male	71.43	58.33	83.33	42.86	100.00	57.14	66.67	71.43	100.00	75.00	75.00	88.89	0.74
	Female	19.48	33.33	16.67	42.86	0.00	28.57	16.67	28.57	0.00	0.00	12.50	11.11	
	Both	9.09	8.33	0.00	14.29	0.00	14.29	16.67	0.00	0.00	25.00	12.50	0.00	
Harvesting	Male	48.05	50.00	50.00	71.43	25.00	14.29	66.67	85.71	100.00	75.00	12.50	11.11	0.05
	Female	41.56	41.67	33.33	14.29	50.00	71.43	16.67	14.29	0.00	12.50	75.00	88.89	
	Both	10.39	8.33	16.67	14.29	25.00	14.29	16.67	0.00	0.00	12.50	12.50	0.00	
Sale	Male	57.14	58.33	66.67	42.86	50.00	42.86	66.67	57.14	33.33	75.00	62.50	55.56	1.00
	Female	22.08	25.00	16.67	28.57	25.00	28.57	16.67	14.29	33.33	12.50	25.00	22.22	
	Both	20.78	16.67	16.67	28.57	25.00	28.57	16.67	28.57	33.33	12.50	12.50	22.22	
Processing	Male	23.38	16.67	66.67	28.57	25.00	42.86	16.67	42.86	0.00	12.50	25.00	22.22	0.99
	Female	62.34	75.00	66.67	42.86	50.00	42.86	66.67	42.86	100.00	75.00	62.50	66.67	
	Both	14.29	8.33	16.67	28.57	25.00	14.29	16.67	14.29	0.00	12.50	12.50	11.11	

The level of significance is (p < 0.05)

Table 5. Gender-wise rights to harvesting, marketing, processing and tree ownership in selected agroforestry systems of Ayodhya district, Uttar Pradesh

Activities	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Harvesting	Male	48.05	50.00	50.00	71.43	25.00	14.29	66.67	85.71	100.00	75.00	12.50	11.11	0.05
	Female	41.56	41.67	33.33	14.29	50.00	71.43	16.67	14.29	0.00	12.50	75.00	88.89	
	Both	10.39	8.33	16.67	14.29	25.00	14.29	16.67	0.00	0.00	12.50	12.50	0.00	
Marketing	Male	57.14	58.33	66.67	42.86	50.00	42.86	66.67	57.14	33.33	75.00	62.50	55.56	1.00
	Female	22.08	25.00	16.67	28.57	25.00	28.57	16.67	14.29	33.33	12.50	25.00	22.22	
	Both	20.78	16.67	16.67	28.57	25.00	28.57	16.67	28.57	33.33	12.50	12.50	22.22	
Processing	Male	23.38	16.67	16.67	28.57	25.00	42.86	16.67	42.86	0.00	12.50	25.00	22.22	0.99
	Female	62.34	75.00	66.67	42.86	50.00	42.86	66.67	42.86	100.00	75.00	62.50	66.67	
	Both	14.29	8.33	16.67	28.57	25.00	14.29	16.67	14.29	0.00	12.50	12.50	11.11	
Tree ownership	Male	50.65	50.00	50.00	71.43	50.00	42.86	50.00	28.57	100.00	50.00	50.00	44.44	1.00
	Female	32.47	33.33	33.33	14.29	25.00	42.86	33.33	42.86	0.00	37.50	37.50	33.33	
	Both	16.88	16.67	16.67	14.29	25.00	14.29	16.67	28.57	0.00	12.50	12.50	22.22	

The level of significance is (p < 0.05)

Table 6. Factors hindering gender adoption of agroforestry systems of Ayodhya district, Uttar Pradesh

Factors	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Lack of transportation	Male	51.95	41.67	33.33	71.43	50.00	42.86	50.00	57.14	33.33	62.50	50.00	66.67	0.57
	Female	18.18	0.00	33.33	14.29	25.00	28.57	16.67	42.86	33.33	12.50	0.00	22.22	
	Both	29.87	50.00	33.33	14.29	25.00	28.57	33.33	0.00	33.33	25.00	50.00	11.11	
Limited business and negotiation skills	Male	51.95	41.67	33.33	71.43	50.00	42.86	50.00	57.14	33.33	62.50	50.00	66.67	0.91
	Female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Both	48.05	50.00	66.67	28.57	50.00	57.14	50.00	42.86	66.67	37.50	50.00	33.33	
Family opposition	Male	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	Female	51.95	41.67	33.33	71.43	50.00	42.86	50.00	57.14	33.33	62.50	50.00	66.67	
	Both	48.05	50.00	66.67	28.57	50.00	57.14	50.00	42.86	66.67	37.50	50.00	33.33	
Limited products	Male	42.86	41.67	33.33	57.14	25.00	28.57	50.00	42.86	33.33	50.00	50.00	44.44	
	Female	12.99	16.67	16.67	14.29	0.00	0.00	33.33	14.29	0.00	12.50	25.00	0.00	
	Both	44.16	33.33	50.00	28.57	75.00	71.43	16.67	42.86	66.67	37.50	25.00	55.56	
High initial investment	Male	45.45	66.67	50.00	14.29	75.00	28.57	16.67	57.14	0.00	50.00	50.00	44.44	0.18
	Female	19.48	16.67	0.00	28.57	0.00	42.86	33.33	14.29	0.00	12.50	25.00	22.22	
	Both	35.06	8.33	50.00	57.14	25.00	28.57	50.00	28.57	100.00	37.50	25.00	33.33	
Lack of extension activities	Male	37.66	33.33	33.33	14.29	50.00	57.14	16.67	57.14	0.00	50.00	62.50	22.22	0.25
	Female	28.57	25.00	0.00	71.43	0.00	14.29	50.00	0.00	66.67	37.50	12.50	44.44	
	Both	33.77	33.33	66.67	14.29	50.00	28.57	33.33	42.86	33.33	12.50	25.00	33.33	
Poor understanding of tree management	Male	40.26	33.33	50.00	0.00	100.00	14.29	33.33	42.86	0.00	50.00	62.50	44.44	0.26
	Female	24.68	25.00	33.33	28.57	0.00	42.86	16.67	28.57	0.00	25.00	12.50	33.33	
	Both	35.06	33.33	16.67	71.43	0.00	42.86	50.00	28.57	100.00	25.00	25.00	22.22	
Limited land availability	Male	31.17	16.67	66.67	0.00	25.00	28.57	16.67	28.57	33.33	37.50	50.00	44.44	0.18
	Female	23.38	33.33	0.00	42.86	0.00	42.86	0.00	42.86	33.33	0.00	12.50	33.33	
	Both	45.45	41.67	33.33	57.14	75.00	28.57	83.33	28.57	33.33	62.50	37.50	22.22	
Limited cash availability	Male	31.17	33.33	0.00	57.14	0.00	14.29	33.33	42.86	0.00	37.50	25.00	55.56	
	Female	40.26	25.00	100.00	14.29	25.00	57.14	50.00	42.86	33.33	37.50	50.00	22.22	
	Both	28.57	33.33	0.00	28.57	75.00	28.57	16.67	14.29	66.67	25.00	25.00	22.22	
Absence of a guiding policy on agroforestry	Male	35.06	33.33	50.00	14.29	75.00	42.86	16.67	0.00	100.00	12.50	62.50	33.33	0.03
	Female	22.08	33.33	0.00	42.86	0.00	42.86	50.00	0.00	0.00	25.00	0.00	22.22	
	Both	42.86	25.00	50.00	42.86	25.00	14.29	33.33	100.00	0.00	62.50	37.50	44.44	

The level of significance is (p < 0.05)

Table 7. Gender-wise recommendations for adoption of agroforestry systems in Ayodhya district, Uttar Pradesh

Recommendations	Gender	Overall (n=77) (%)	Milkipur (n=12) (%)	Sohawal (n=6) (%)	Harringtonganj (n=7) (%)	Mawai (n=4) (%)	Rudauli (n=7) (%)	Mayabazar (n=6) (%)	Bikapur (n=7) (%)	Masodha (n=3) (%)	Purabazar (n=8) (%)	Amaniganj (n=8) (%)	Tarun (n=9) (%)	p-value
Develop infrastructure for transport & storage	Male	35.06	50.00	50.00	28.57	50.00	42.86	16.67	28.57	33.33	37.50	12.50	33.33	0.63
	Female	22.08	16.67	16.67	14.29	0.00	42.86	66.67	14.29	33.33	12.50	25.00	11.11	
	Both	42.86	33.33	33.33	57.14	50.00	14.29	16.67	57.14	33.33	50.00	62.50	55.56	
Training on production of value-added products	Male	37.66	33.33	33.33	28.57	25.00	28.57	16.67	42.86	33.33	62.50	37.50	55.56	
	Female	18.18	16.67	16.67	28.57	25.00	0.00	16.67	28.57	0.00	12.50	25.00	22.22	
	Both	44.16	50.00	50.00	42.86	50.00	71.43	66.67	28.57	66.67	25.00	37.50	22.22	
Training in tree management	Male	59.74	66.67	66.67	57.14	50.00	85.71	83.33	57.14	66.67	50.00	37.50	44.44	
	Female	40.26	33.33	33.33	42.86	50.00	14.29	16.67	42.86	33.33	50.00	62.50	55.56	
	Both	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Easy micro-credit arrangement	Male	15.58	16.67	16.67	14.29	0.00	14.29	16.67	28.57	0.00	25.00	0.00	22.22	0.98
	Female	18.18	16.67	16.67	28.57	25.00	0.00	16.67	28.57	0.00	12.50	25.00	22.22	
	Both	66.23	66.67	66.67	57.14	75.00	85.71	66.67	42.86	100.00	62.50	75.00	55.56	
Policy interventions	Male	20.78	16.67	33.33	14.29	0.00	14.29	16.67	28.57	0.00	37.50	0.00	44.44	0.70
	Female	41.56	50.00	50.00	57.14	75.00	42.86	16.67	42.86	33.33	25.00	37.50	33.33	
	Both	37.66	33.33	16.67	28.57	25.00	42.86	66.67	28.57	66.67	37.50	62.50	22.22	

The level of significance is (p < 0.05)

significant difference across the blocks for limited product, poor understanding of tree management, limited land availability and absence of a guiding policy on agroforestry as a hinderance in agroforestry systems adoption. Birhanu and Guye (2022) concluded that limited product was seen as a major hindrance by males. The limited cash availability across all the blocks was seen as a hindrance, the highest by females and least by both gender and it was not statistically significantly different across the blocks. Across all the blocks, implication of development of infrastructure for transport and storage, training on production of value-added products were seen as interventions, the highest in both genders and least by females (Table 7). There was no statistically significant difference across the blocks for infrastructure development and training on production as interventions. Catacutan and Naz (2015) in Northwest Vietnam, observed that males recommended for better infrastructure for transport and storage in agroforestry systems as compared to that of females. Birhanu and Guye (2022) concluded that females perceived training on production of value-added products as a major intervention than males. Training in tree management was reported to be the foremost requirement, the highest by the males and the least by both the genders. Implication of easy micro-credit arrangement was seen as the intervention the highest in both genders and least by males and there was no statistically significant difference across the blocks for micro-credit arrangement. Implication of policy interventions was seen as an intervention, the highest in females and least by males but it was not statistically significantly different across the blocks.

CONCLUSION

The agroforestry practices in Ayodhya district were still men-centric and men-dominated. Males were involved in agroforestry activities such as ploughing, tree planting, fertilization, pruning, harvesting, transport and sales and had higher access to land ownership, land transfer rights, loans and irrigation facilities. The decision on planting of species, which area to plant, how many numbers of plants to be planted, irrigation, pruning, harvesting and sale were mostly taken by males. They also enjoyed the rights of harvesting, marketing and tree ownership. Lack of transportation, limited business and negotiation skills, high initial investment, lack of extension activity were seen as hindrances in adoption of agroforestry systems according to the males of the region and were of the opinion that interventions such as easy micro-credit arrangement, development of infrastructure for transport and storage, training on production of value-added products could help in faster adoption of the system. Females preferred fruit bearing trees whereas the men preferred

timber-yielding trees. The decision on season of planting, financial management, fertilizer application and processing were mostly taken by females and they enjoyed the right of processing of agroforestry products. The family opposition and limited cash availability were seen as hindrances by the females in adoption of agroforestry systems and they stressed on policy interventions to improve the adoption rate of agroforestry systems. This study revealed that the societal pressure on females still exists in this region which restricted the females from becoming financial independent and decision makers. So, a high level policy intervention and changes in social behaviour and attitudes is required to cherish the dream of women empowerment in this region.

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Influence of Bund Planted Teak (*Tectona grandis* L. f.) Trees on Field Crops in Semi-Arid Tropics

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Abstract: Field experiment was conducted to observe the influence of bund planted teak trees on field crops during 2021-22 in Agroclimatic Zone-2 (North-Eastern Dry Zone) of Karnataka, India. Treatment consists three distances from tree 2-6 m, 6-10 m 10-14 m and subplots three crops greengram, blackgram and pigeon pea. Significantly lower yield attributing characters such as plant height, number of branches per plant and number of pods per plant of green gram, pigeon pea and black gram respectively were recorded near the tree line at 2-6 m and were increased with increase in distance from the tree line and at distance to 10-14 m and were on par with the control (without trees). However, significantly lower grain yield of green gram and pigeon pea (456 kg ha^{-1} and 1166 kg ha^{-1} respectively) were near tree line and were increased with increase in distance from tree line and at distance 10-14 m grain yields of green gram and pigeon pea were on par with the control (without trees). Grain yield of black gram did not differ significantly over distances from tree line but numerically lower grain yield of black gram was noticed near tree line. The pooled average reduction in yield of green gram, pigeon pea and black gram were 16, 9 and 2 per cent respectively as compared to control. The significantly higher soil organic carbon content, available N, P$_2$O$_5$ and K$_2$O (0.42%, 382, 38 and 413 kg ha^{-1}, respectively) were near the tree line and were decreased with increase in distance from the tree line and at distance 10-14 m parameters were on par with control. In all the negative and positive influence on associated crops and soil properties respectively were extended up to 10 m distance from the tree line and among the crops black gram was least affected followed by pigeon pea and green gram.

Keywords: Teak, Bund planting, Influence, Field crop and pigeon pea

Farmers are showing keen interest in growing economical tree species in association with agriculture crops in the form of bund and boundary planting and in some instances as wood lots (block plantations) with an intension to get good returns in long run (Doddabasawa et al 2020). Further, growing of trees are influenced by heterogeneous factors like socio-economic condition of the farmer, ecological condition of the area, competitive and complementary effects of trees and more importantly utility and economic value of the species (Giller et al 2006). Among few economical tree species, teak (*Tectona grandis* L. f.) is widely grown by the farmers especially in southern part of India. Similarly, farmers have grown *Alnus nepalensis* in Himalayan region of India (Rita et al 2007), *Prosopis cineraria* with millets in Rajasthan (Tejwan 1994) and *Populus deltoids* with wheat in Western India (Chaun et al 2015) and farmers preferable interested to grow high valued timbers (Nyaga et al 2015).

Teak wood is durable and most admired and precious tree used widely from furniture to interior architecture and therefore teak tree is being listed as top priority species in more than 20 countries and is being grown over 70 countries (Walter and Michael 2017). Teak being mesic-deciduous species having thin crown with little spread and deep root system are considered to be most suitable species for small holding farmer (Pinyarat et al 2021). However, growing trees on bunds have both complimentary and competitive effects particularly on field crops and soil in general (Chittapur et al 2017). Further, response of field crops also varies. Thus, understanding the tree crop interaction is necessary to take up management strategies such pruning, thinning, crop selection and other practices. Hence, the present investigation was undertaken to know the influence of bund planted teak trees on pulse crops such as green gram, pigeon pea and black gram and as well as on soil chemical properties in North-Eastern Dry Zone of Karnataka.

MATERIAL AND METHODS

The study was under taken during 2021-22 in Yadgir district of North eastern dry zone (Zone II) of Karnataka at Agricultural Research Station, Bheemarayanagudi. The climate of the region is dry semi-arid with cool winters and dry hot summers. The average rainfall is around 750 mm and mean annual temperatures range from 18.6 to 32.5°C and mean elevation ranges from 350-680 m. The soils are deep to very deep black soils and medium black soils in major areas

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while sandy loam and light textured soils are also found in some pockets. However, the soil of the study site was medium black cotton soils The three pulse crops viz., green gram, black gram and pigeon pea were chosen for the experiment and were grown under rainfed conditions. The experiment was laid out in gross plot size 5.4 m X 5.0 m and net plot size 3.6 m X 4.0 m and sample plots were laid out randomly with 3 replications at distance of 2-6m, 6-10 m and 10-14 m, respectively from the tree line and total plots laid were nine for each crop, whereas in control (sole crop) three plots were laid out randomly in the entire field for each crop. The crops green gram (cv. BGS9), black gram (cv. TAU1) and pigeon pea (cv.TS3R) were sown during *kharif* 2021-22 with spacing of 30X10 cm, 30X10 cm and 90X10 cm respectively. Productivity of field crops such as plant height, number of branches per plant, number of pods per plant and grain yield were recorded with a net plot and the mature crop was harvested at ground level, later grain and haulm were separated. Further, they were dried and weighed and were computed, averaged and extrapolated to per ha basis. The teak trees were planted on bund in North- South direction with 45 trees running at a length of 100 m and the trees were of 12 years old with an average height of 8.58 m and average girth of 62.80 cm. However, crops were sown on the western direction of tree line. For soil chemical properties, the composite soil samples from 0-15 depths at 2 to 6.0, 6.0 to 10.0 and 10.0 to 14.0 m distance from the base of the tree towards western directions of the tree line were collected

after harvest of crop from each plot for the estimation organic carbon (%) and available nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) (kg ha^{-1}). At the same time, soil samples were also collected from sole crop (without trees) for comparison of the nutrient status. The data was analyzed using Duncan test at significance level of 0.05 by using SPSS (Statistical Package for Social Science) version 20.0.

RESULTS AND DISCUSSION

The investigation on the influence of bund planted teak (*Tectona grandis* L. f) trees on greengram, blackgram and pigeon pea at different distances from tree line on western direction revealed significant differences. Significantly lower plant height of greengram, blackgram and pigeonpea (40.60, 44.20 and 96.20 cm respectively) were near tree line at distance of 2-6 m and were increased with increase in distance from tree line and at distance 10-14 m and were on par with control (without trees). The significantly lower number of branches per plant of pigeon (4.80 plant^{-1}) were near the tree line. The number of branches per plant of green gram and black gram did not differ significantly. The significantly lower number of pods per plant of green gram and pigeon pea (11.20 and 75.60 plant^{-1}respectively) were near the tree line at distance 2-6m whereas in black gram number of pods per plant did not differ significantly. The lower plant growth attributes near the tree could be due to the competitive effect of trees for light, moisture and nutrients with field crops. However, among the crops black gram was

Table 1. Methodologies used for analysis of soil chemical properties

Parameters	Methodology	Reference
pH	1:2.5 soil water suspension with the help of digital pH meter	Jackson (1973)
EC (dS m^{-1})	1:2.5 soil water suspension using conductivity bridge	Jackson (1973)
OC (%)	Walkley and Black rapid titration method	Walkley and Black (1934)
Available N (kg ha^{-1})	Alkaline potassium permanganate method	Subbaiah and Asija (1956)
Available P_2O_5 (kg ha^{-1})	Spectrophotometric method (Olsen Extraction Method with 0.5 M $NaHCO_3$, pH of 8.5)	Jackson (1973)
Available K_2O (kg ha^{-1})	Flame-Photometric method (Extraction with NH_4OAC of pH 7)	Jackson (1973)

Table 2. Influence of bund planted teak (*Tectona grandis* L. f.) trees on yield attributing characteristics of green gram (*Vigna radiata*), black gram (*Vigna Mungo*) and pigeon pea (*Cajanus cajan*) at different distances from tree line

Treatment	Plant height (cm)	No. of branches/plant	No. of pods/plant	Plant height (cm)	No. of branches/plant	No. of pods/plant	Plant height (cm)	No. of branches/plant	No. of pods/plant
Field crops		Green gam			Black gram			Pigeon pea	
D$_1$ (2-6m)	40.60[a]	2.20[a]	11.20[a]	44.20[a]	3.60[a]	24.20[a]	96.20[a]	4.80[a]	75.60[a]
D$_2$ (6-10m)	52.20[b]	3.20[b]	17.40[b]	48.00[b]	4.00[b]	27.60[abc]	109.40[b]	6.00[ab]	96.40[b]
D$_3$ (10-14m)	59.20[c]	3.40[b]	24.00[c]	52.80[c]	4.40[b]	28.80[abc]	127.80[c]	7.20[b]	104.80[b]
Control (without trees)	58.60[c]	3.40[b]	25.00[c]	55.20[c]	4.60[b]	31.00[c]	129.40[c]	7.40[b]	105.40[b]

least affected with respect to the number of branches per plant and number of pods per plant could be due to black gram plant grows quite erect and hairy structure on leaf and pods might have contributed to with stand moisture scarcity. The grain yield was significantly lower in green gram and pigeon pea (456 kg ha^{-1} and 1166 kg ha^{-1}respectively) near tree line at distance 2-6m and were increased with increase in distance and at distance 10-14m grain yield were on par with the control (without trees). Grain yield of black gram was non-significant. The lower grain yield of green gram and pigeon pea near the tree line could be due to shading and competitive effect of trees for light, moisture and nutrients. Among the crops black gram was least affected as compared to the pigeon pea followed by green gram. This could be due physiological characteristics of black gram which has erect growing, hairy structures on leaves and pods and deep root system as compared to pigeon pea and green gram and as well as higher number of branches and pods per plant of black gram might have contributed to higher grain yield (Nanadal and Singh 2001). The pooled yield over distances as compared to the control (without trees) indicated reduction of grain yield of green gram, pigeon pea and black gram by 16, 9 and 2 per cent respectively. However, significantly higher percent yield reductions of green gram, pigeon pea and black gram (36, 20 and 10 per cent respectively) were near the tree line at distance of 2-6m as compared at other distances as compared to control (without trees). This could be more shade near the tree line and among the crop higher reduction was observed in green gram followed by pigeon

pea whereas least reduction was observed in black gram (Patil and Channabasappa, 2008) Thus, black gram is most suitable crop followed by pigeon pea and green gram. Further, green gram is seems to be more sensitive to shade as compared to pigeon pea and black gram.

The influence of bund planted teak (*Tectona grandis*L. f) trees on soil chemical properties at different distances revealed that soil pH and EC did not differ significantly with respect to distances. Further, numerically lower soil pH and EC were recorded near tree line and increased with increase in distance from the tree line and were on par with the control (without trees) (Table 4). This indicates that trees did influence much on these properties as the trees are of 12 years old. Significantly higher soil organic carbon (0.42%) was near the tree line at distance 2-6m and was decreased with increase in distance from the tree line and at distance 10-14 m was on par with the control (Without trees). The higher organic carbon content near tree line and upper surface of the soil layer could be attributed due to continuous addition of organic matter by trees on upper layers and was more near the tree line as compared to away from tree line. Similarly, significantly higher available N, P_2O_5 and K_2O (236.50, 19.13 and 222.24 kg ha^{-1}, respectively) were recorded near the tree line at distance 2-6 m and were decreased with increase in the distance from the tree line and at distance D_3 (10-14 m) were on par with control . The higher status of nutrients near the tree line and upper layer of the soil surface could be attributed due to continuous addition of organic matter by trees. Higher nutrients near the tree line might be due to addition of litter by the trees; more often leaf shedding is restricted to its canopy area and as well as by decaying of roots near the tree line. Jones et al (2017) who reported higher available nutrients under *Faidherbia albida* based agri-silviculture system compared to control (without trees). Similarly, Honnayya et al, (2020) found higher organic carbon and available NPK near tree lines and were decrease with increase in distance from the tree line and reported the influence up to 18 m. Doddabasawa et al, (2017) observed significantly higher organic carbon and available NPK near the tree line in neem based agroforestry systems over control.

Table 3. Influence of bund planted teak (*Tectona grandis* L. f.) trees on grain yield of green gram (*Vigna radiata*), black gram (*Vigna Mungo*) and pigeon pea (*Cajanus cajan*) at different distances from tree line (Grain yield kg ha^{-1})

Treatment	Green gram	Black gram	Pigeon pea
D$_1$ (2-6m)	456^a	662^{ab}	1166^a
D$_2$ (6-10m)	633^b	715^{abc}	1406^b
D$_3$ (10-14m)	713^b	725^{abc}	1433^b
Control (Without trees)	714^b	737^c	1474^b

Table 4. Influence of bund planted teak (*Tectona grandis* L. f.) trees on soil chemical properties at different distances from tree line on western direction

Treatment	P^H 1:2.5 (soil: water)	EC (ds/m)	Organic carbon (%)	Avl. N (Kg/ha)	Avl. P$_2$O$_5$ (Kg/ha)	Avl. K$_2$O (Kg/ha)
D$_1$ (2-6m)	8.14^a	0.45^a	0.42^a	382^a	38^a	413^a
D$_2$ (6-10m)	8.16^a	0.47^a	0.31^b	308^b	26^b	378^b
D$_3$ (10-14m)	8.20^a	0.48^a	0.23^c	255^c	23^{bc}	295^{bc}
Control (Without trees)	8.22^a	0.48^a	0.21^c	228^d	21^c	282^c

CONCLUSION

The present investigation on influence of bund planted teak trees on field crops indicated significantly lower yield of crops near tree line at 2-6 m and were increased with increase in distance and no effect at distance of 10-14m. The black gram was least affected followed by pigeon pea and green gram. However, significantly higher nutrient status was near the tree line and were decreased with increase in distance from the tree line, over all the negative and positive effects by the bund planted teak trees were extended up to 10 m distance from the tree line.

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Rediscovery of Swamp Deer *Rucervus duvaucelii* (G. Cuvier, 1823) in Kumaon Region of Uttarakhand State of India

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Abstract: Swamp deer *R. d. duvaucelii* with its lighter coat, un-palmate antlers and larger hoof known to occur in the soft swampy ground of Himalayan foothills encompassing the forests of Terai Arc Landscape. Mostly, isolated population of Swamp deer reported from the state of Uttar Pradesh state of India and in the recent past scattered population reported from the Garhwal region of Uttarakhand state. Available literature shows distribution of swamp deer from various pockets of Kumaon region of Uttarakhand but in the present time its existence was doubtful due to lack of evidence or a direct sighting. Advances in scientific based techniques and tools for the monitoring of elusive and cryptic wild species provides an opportunity to document rarely seen and occurring in low abundance species. The reappearance of swamp deer based on a by-catch of camera traps from the Kumaon region of Uttarakhand is reported here.

Keywords: *Rucervus eldi, Rucervus schomburgki,* Swamp deer, Kumaon, Uttarakhand

Swamp deer is endemic to the Indian sub-continent and shares its species group with the brow-antlered deer *Rucervus eldi* and the now-extinct Schomburgk's deer *Rucervus schomburgki*. These species are believed to have evolved in the Indo-Chinese and Malayan sub-regions, where they have adapted to thrive in swampy grassland conditions (Mani 1974). Blanford (1888-91) documented the distribution of the Swamp deer. Subsequently, three subspecies of swamp deer were identified (Brander 1923, Ellerman and scott 1951, Groves 1982). These subspecies include *R. d. duvaucelii*, which inhabits the swampy grasslands of Northern India and Nepal; *R. d. branderi,* which occupies the hard ground of Central India; and *R. d. ranjitsinhi,* which prefers marshes and grasslands in the Brahmaputra flood plains. It is important to note that swamp deer is already extinct in Pakistan and Bangladesh (Qureshi et al 2004). Historically, swamp deer were found across a vast range, from the foothills of the Himalayas in the North to the Godavari River in the South. In the East, their habitat extended from the Brahmaputra alluvial floodplains to the marshy areas of the Sundarbans, and in the West, their presence reached the Indus River. In 1967, Schaller narrowed down the occurrence of swamp deer to 28 specific sites in India and Nepal. Out of these 28 sites, 11 were represented by the *R. d. duvaucelii* sub-species and were primarily located in Northern India. However, the range of the swamp deer continued to diminish over time. Holloway (1973), reported only four surviving population of the swamp deer in Northern India, located in Pilibhit, Bahraich, North and South Kheri, all within the Uttar Pradesh state of India. In addition to these four localities, swamp deer populations in Uttar Pradesh were also recorded in the Hastinapur Wildlife Sanctuary and its surrounding areas along the River Ganges, as well as near Afzalgarh (Bijnor district) in the marshy area of the Ramganga River (Paul et al 2018). In the state of Uttarakhand, swamp deer were rediscovered on 1st February, 2005, in the Jhilmil Jheel area, close to Haridwar town, which falls under Haridwar Forest Division under Garhwal region of the state. Later on, this area was declared as a conservation reserve for swamp deer on 14th August, 2005 (Sinha and Chandola 2006). Here we are reporting rediscovery of swamp deer from the Kumaon region of the Uttarakhand state based on photographic evidence (Fig. 1).

MATERIAL AND METHODS

Study was carried out in an important wildlife corridor which connects forests of Nandhaur Wildlife Sanctuary with the Pilibhit Tiger Reserve in Uttar Pradesh state. This corridor is known as Kilpura-Khatima-Surai and also provide connectivity with the Shuklaphanta National Park through Sharda River and agroforestry mosaic in Nepal (Anwar and Borah 2019). Corridor area was divided into 2.04 sq km grid framework for the deployment of camera traps. A total of 66 pairs of camera traps were deployed between September 14, 2014 and October 3, 2014, in three forest ranges, namely Kilpura, Khatima and Surai within the Terai East Forest

Division (Fig. 2). Camera traps were operational 24x7 for 20 days session and were regularly monitored. Data downloaded and collated folder wise with unique identity designating corresponding camera stations. All the photographs of the animals manually segregated to the species level with the help of available check list of the area and doubtful species were later identified with the help of field guide (Menon 2014).

RESULTS AND DISCUSSION

This study primarily aimed at estimating the tiger population. During the camera trap survey, we captured three photographs of the swamp deer at two different camera locations in Kilpura range (Fig. 3). The first photograph, taken at camera point number 7, was recorded on 30th September 2014 at 23:44 hrs. The second photograph was captured at camera point number 11 on 1st October 2014, at 01:04 hrs. Lastly, the third photograph of the swamp deer was captured on 2nd October 2014, at 04:16 hrs at the same camera point. These camera pairs were deployed along the fire line in a sal *Shorea robusta* dominated forest. Other trees species present included *Mallotus philippensis, Acacia catechu, Terminalia chebula,* and *T. tomentosa*. The ground cover was predominately composed of *Cassia tora, Lantana camara, Flemingia* sp. etc. The area represented a typical bhabhar zone, with seasonal water bodies and stream located approximately 4 to 5 kilometers to the south of the camera sites.

Historically, the swamp deer population in the Jaulasal, Lalkuan, and Maldhan Sanctuaries witnessed a significant decline as reported by Holloway in 1973. Factors contributing to this decline included poaching and habitat loss due to the planting of exotic species like *Eucalyptus* and the conversion of forest land into crop fields (Holloway 1973). Since then, this is the first photographic evidence of
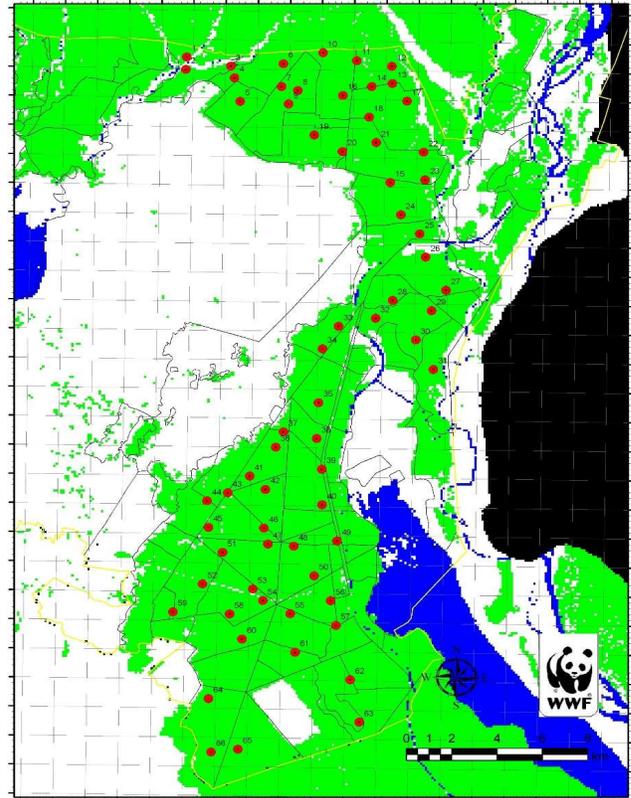

Fig. 2. Grid design for the placement of the camera traps and sites of capture of swamp deer (camera point 7 & 11)
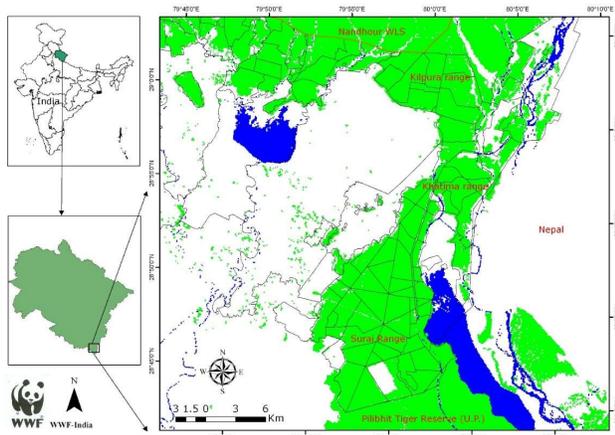

Fig. 1. Location map of the study area

Fig. 3. Swamp deer photo-captured in Kumaon region

the swamp deer's presence in the Kilpura range, which adjoins the recently declared (2012) Nandhaur Wildlife Sanctuary. This significant record might have gone unnoticed if all the photographs of wild animals accumulated during the study were not sorted at the species level. Recent advancements in camera trap data management software have the potential to lead to more discoveries like this one within the scientific community. Present report provides a strong base for carrying out thorough occupancy survey of swamp deer in the Himalayan foothills of the Kumaon region in the Uttarakhand state. Additionally, it emphasizes the need to implement conservation management practices for swamp deer within the Nandhaur Wildlife Sanctuary and adjoining reserved forest areas. Reclaiming and restoring the marshy areas under Nandhaur Wildlife Sanctuary and enhanced protection level is recommended for rebounding of swamp deer population in the Kumaon region of Uttarakhand. The swamp deer is listed as 'Vulnerable' in IUCN Red list of threatened species (Duckworth et al 2015) and Schedule I species under Wildlife Protection Act, (1972) of India.

CONCLUSION

Swamp deer is habitat specialist species, prefers marshes and grassland (Sankaran 1990). Terai Ecosystem is characterized by low water table, enabling creation of typical habitat for swamp deer. Rampant destruction of this ecosystem for agricultural practices, industrialization, development of linear infrastructure, and human settlement has led to large scale fragmentation, shrinkage, and isolation of such habitat resulting in decline of population of habitat specialist species such as swamp deer, Bengal florican and hispid hare. Additionally, forestry policies considered grassland as suitable places for carrying out target-based plantations and introduced exotic species of trees such as

Eucalyptus (Rahmani et al 1988), which completely changed the habitat at its micro climate level. Present report of swamp deer from the Kumaon provide us another opportunity to reclaim, and restore habitat of swamp deer in the Himalayan foothills, actively manage and conserve this endemic species by establishing a breeding center in Uttarakhand.

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Floristic Diversity of Sunni Dam Catchment in North Western Himalayas

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Abstract: The present investigation was conducted during July- September, 2021-22 in the vicinity of proposed Sunni Dam which falls under Shimla and Mandi districts of Himachal Pradesh wherein the panchayats closer to the dam area were considered with objectives to document the floristic diversity in the dam catchment. The study revealed that overall, 20 trees, 21 shrubs and 21 herbaceous species were recorded from the study area. The floral enumeration revealed that the tree density was highest (62.67/ha) in village Parlog and lowest (41.33/ha) in Khaira. Among the shrub layer, the highest density was observed in village Parlog whereas lowest in Khaira. The Shannon diversity index for the tree was highest (2.2) in Parlog and lowest (1.66) in village Khaira. The shrub diversity index was highest (1.81) in Bathora and lowest (1.13) in Khaira. The herb diversity was highest (1.98) in Bathora and lowest (1.81) in Parlog. The area with the highest floristic diversity and density will have a greater risk of being affected after the dam construction. This study would be considered a supportive tool for compensatory afforestation planning as well as baseline for any further research in this area.

Keywords: Diversity, Dam, Species, Flora, Baseline, Afforestation planning

The planet Earth is bestowed with a substantial diversity of life form that forms a basic foundation for life to exist on Earth (Bhatt 2021). Biodiversity is one such gift of nature that is responsible for humans' survival on the planet. It is not only responsible for stabilizing the ecosystem but also contributes to strengthening the economy of the nation (Alfagham et al 2022). Floristic diversity regulates a lot of provisioning and supporting ecosystem services. It is a reflection of a healthy ecosystem as well as it influences the other biotic factors. It is a consequence of actions to environmental filtering (Zheng and Zheng 2022). The plant community plays an important role in the management of biodiversity as well as in environmental conservation (Galal et al 2021). Floristic diversity serves as the basis for the entire ecosystem. However, various developmental activities like dams, roads and highway construction are well known threats to biological diversity through habitat degradation (Chaudhari and Pathak 2022, Rajkumar and Ravipaul 2022). Thus evaluation of the number of species in a particular community is a significant factor in determining the biodiversity status of that region and indirectly also helpful in assessing the loss of floral diversity due to such activities. Hence, assessment of biological diversity was done in terms of numerous phytosociological parameters.

Himachal Pradesh being situated in the lap of the Himalayas has huge potential for hydro-power generation thus a lot of hydro-power projects and dams are being proposed continuously and hence affecting the native floral diversity of the region. Therefore, keeping in view the above facts the present investigation was carried out around proposed Sunni dam in Himachal Pradesh situated in Indo-Himalayan region. The study aimed to assess the loss of native floral diversity due to submergence under proposed dam. Analysis of floral diversity of a region is helpful in protecting the native flora of a particular region. Keeping in view the above facts the present study was carried out with the objective to assess the floristic diversity of the region around the Sunni dam hydropower project.

MATERIAL AND METHODS

Study site: The present investigation was carried out in the Shimla and Mandi districts of Himachal Pradesh in order to assess the floral diversity around the proposed dam of the Sunni hydro-power project of 382 MW capacity. The dam is proposed in the inner lesser Himalayas between the Dhaula Dhar range in the south and the higher Himalayan range in the north. It is located in Himachal Pradesh at a longitude of 77˚12'39'' E and a latitude of 31˚14'53'' N. Sub-tropical type of microclimate prevailed in the region. The study area comprised community land of three village panchayats Bathora, Khaira and Parlog in close vicinity to the dam. The selected villages come under the jurisdiction of the Mandi and Shimla districts. Village Khaira is situated in the closest proximity of dam within 1 km followed by Parlog at 6.8 km and Bathora at a distance of 8.2 km (Fig. 1).
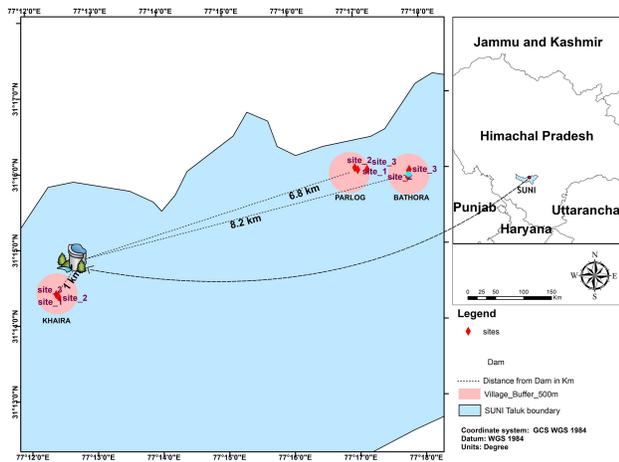
Fig. 1. Study area

Vegetation analysis: The field survey and assessment of floral diversity was carried out during the year 2022 from July to September in the vicinity of proposed dam. The species count methodology was employed for enumerating the species in the study area. The data was collected by marking 50 × 50 m plots in each village of study areas. Ten quadrats of 10×10 m for the enumeration of tree species, ten quadrats of 5×5m for shrubs and ten quadrats of 1×1m for herbs were randomly laid within the plots and plant community was studied for their quantitative character. The trees, shrubs and herbaceous vegetations were noted to keep an account of the floral composition of the plot

Density: Number of Individual of a species per unit area and is calculated Ghafari et al (2020).

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$$

Frequency: The degree of dispersion of an individual species in a community, i.e. chance of occurrence of species in each habitat is frequency (F) and expressed in per cent. The frequency was calculated (Raunkiaer 1934).

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}}$$

Relative density: Relative density (RD) is per cent representation of a species in term of number of individuals relative to all other species in a community.

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \times 100$$

Relative frequency

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

Relative dominance

$$\text{Relative dominance (\%)} = \frac{\text{Total basal area of a species}}{\text{Total basal area of all species}} \times 100$$

All the above three parameters of relative density, relative frequency and relative dominance were calculated using formulae given by Misra, 1968.

Importance Value Index (IVI): It reflects the sociological structure of a species in a community as it indicates its importance in the community. The importance value index was calculated using standard procedure given by (Curtis 1959, Kershaw 1973).

IVI = Relative frequency + Relative density + Relative dominance

Species diversity: the species diversity index was calculated using the following formula (Shannon and Weaver 1963)

$$\text{Species diversity} = H = \sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N}$$

Where, s= number of species, n_i = the abundance of the nth species.

N= the total abundance of each species

Concentration of dominance:

Concentration of dominance (cd) as per Simpson's index (Simpson 1949).

CD= $\Sigma (N - N)^2$

Where, n= the total number of individual particular species,

N= the total number of organisms of all species

RESULTS AND DISCUSSION

Phytosociological description of tree species: Overall 10 species were recorded in Khaira village (Table 1). Among trees *Leucaena leucocephala* has the highest tree density (10.33 ind/ha) whereas the lowest density (0.67 ind/ha) was of *Dalbergia sissoo*. Similarly, the frequency and total basal area were also highest for *Leucaena leucocephala* (43.33%, 1.032 m²/ha) whereas the lowest frequency (6.67%) was for *Dalbergia sissoo*. *Phyllanthus emblica* and *Phoenix sylvestris* has the lowest total basal area. Further, irrespective of the species, the total basal area was 3.292 m²/ha. The importance value index IVI was 75.51, 54.16 and 51.09 for *Leucaena leucocephala*, *Acacia catechu* and *Ficus palmata*, respectively.

In Bhatora village total of 15 tree species were observed out of which the highest density (14.67 ind/ha) was for *Grewia optiva*, whereas *Phyllanthus emblica*, *Pinus roxburghii* and *Jacaranda mimosifolia* has the lowest density (0.33 ind/ha) (Table 2). Further, the highest frequency (60%) was observed for *Leucaena leucocephala* and *Phyllanthus emblica* whereas the lowest was 3.33% for *Pinus roxburghii* and *Jacaranda mimosifolia*. The data pertaining to IVI revealed that a mixed community with codominance of *Grewia optiva* and *Leucaena leucocephala* with IVI values of 99.92 and 93.69 was observed. In Parlog village 14 tree species were

recorded out of which *Grewia optiva* has the highest density of 13 individual/ha, whereas the *Phoenix sylvestris* sowed lowest density (0.33/ha) (Table 3). The highest frequency and total basal area were observed for *Grewia optiva* (46.67%, 2.363 m²/ha) and the lowest (3.33%, 0.001 m²/ha) was observed for *Phoenix sylvestris*. The most dominant species *Grewia optiva* (80.10) followed by *Leucaena leucocephala* and *Ficus palmata* respectively (Fig. 2).

The vegetation analysis of tree species from the selected villages in the vicinity of the sunni hydro-power dam area revealed that among selected villages the highest number of tree species was in Bathora whereas the lowest in Parlog. The tree density was highest for village Parlog and lowest in Khaira. The total basal cover was highest in Bathora. Similar study on phytosociological assessment of species has also been carried out in previous years wherein tree density of sub-tropical region ranges between 0.64-300 ind/ha (Sharma and Samant 2013, Kanwal and Joshi 2015, Dhiman et al 2020, Mohapatra et al 2020). However, the importance value index of tree species revealed that *Leucaena leucocephala, Acacia catechu* and *Ficus palmata*, *Leucaena leucocephala* and *Grevia optiva* were the most dominant communities in Parlog, Bathora and Khaira. The highest loss of trees was in Khaira and *Leucaena leucocephala* was the most affected community in study area.

Phytosociological description of shrub species:

The seven shrub species were recorded in the Khaira village (Table 4). *Lantana camara* has the highest density of

Table 1. Phytosociological description of tree species in Khaira village

Trees	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Acacia catechu	6.67	30.00	0.693	1.45	15.56	15.12	23.48	54.16
Bombax ceiba	1.33	10.00	0.040	0.44	3.51	4.76	3.47	11.74
Celtis australis	2.67	13.33	0.097	1.33	6.10	6.85	2.56	15.51
Dalbergia sissoo	0.67	6.67	0.006	0.33	1.75	3.17	0.50	5.43
Ficus palmata	6.67	26.67	0.902	1.64	15.91	15.68	19.51	51.09
Grewia optiva	7.67	30.00	0.388	2.61	18.34	16.44	12.59	47.37
Leucaena leucocephala	10.33	43.33	1.032	2.37	25.10	23.78	26.63	75.51
Phoenix sylvestris	1.67	6.67	0.003	0.83	4.17	4.17	0.07	8.40
Phyllanthus emblica	1.00	6.67	0.007	0.50	2.63	3.17	0.57	6.38
Toona ciliata	2.67	13.33	0.125	1.33	6.93	6.85	10.64	24.42
Total	41.33	18.67	3.292	1.28	100.00	100.00	100.00	300.00

Table 2. Phytosociological description of tree species in Bathora village

Trees	D	F (%)	TBA (m2/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Ailanthus excelsa	2.67	13.33	0.067	1.33	5.75	5.68	1.37	12.79
Bauhinia variegata	1.67	6.67	0.049	0.83	3.27	2.78	0.72	6.77
Bombax ceiba	2.67	20.00	0.064	0.89	5.13	7.87	0.86	13.86
Butea monosperma	1.33	10.00	0.015	0.83	2.90	4.13	0.31	7.34
Ficus auriculata	0.67	6.67	0.007	0.33	1.31	2.78	0.11	4.19
Ficus palmata	1.67	13.33	0.031	0.78	3.37	5.62	0.47	9.46
Grewia optiva	14.67	53.33	4.377	2.74	29.59	21.60	48.73	99.92
Jacaranda mimosaefolia	0.33	3.33	0.001	0.33	0.76	1.45	0.01	2.22
Leucaena leucocephala	14.33	60.00	3.970	2.50	28.91	24.13	40.66	93.69
Mallotus philippensis	3.33	16.67	0.218	1.58	7.26	7.19	4.62	19.07
Phoenix sylvestris	1.67	10.00	0.023	1.17	3.40	3.92	0.25	7.57
Phyllanthus emblica	0.33	3.33	0.0003	0.33	0.65	1.39	0.003	2.05
Pinus roxburghii	0.33	3.33	0.004	0.33	0.63	1.23	0.03	1.89
Syzygium cumini	0.67	6.66	0.001	1.08	1.28	2.62	0.01	3.92
Toona ciliata	3.00	20.00	0.294	0.87	5.79	7.62	1.85	15.26
Total	49.33	16.44	9.122	1.06	100.00	100.00	100.00	300.00

78.33 individual/ha, whereas lowest was of *Berberis lyceum* (2.67 ind/ha). Moreover, the species abundance was highest (16.03) for *Lantana camara* and was lowest 1.50 for *Agave Americana.* Moreover, IVI values revealed that *Lantana camara* was most dominant species with an IVI value of 167.21. In Bathora village 13 shrub species were recorded (Table 5) and *Lantana camara* was the highly dens community with 41.67 individual/ha, whereas *Agave cantala*, *Opuntia monacantha* and *Punica granatum* (0.67/ha) has the lowest density. The IVI value revealed a mixed associated community of *Lantana camara*, *Adhatoda vasica* and *Murraya koenigii* was most dominant species with IVI value of 71.18, 70.24, 58.20, respectively. In Parlog village total of 14 species were recorded (Table 6). The highest density of 54.00 ind/ha was observed in the case of *Lantana camara* whereas *Punica granatum* recorded the lowest (0.67 ind/ha). The data pertaining to IVI revealed that mixed associated community of *Lantana camara* and *Adhatoda vasica* was

recorded with IVI value of 95.48, 70.57, respectively.

The phytosociological assessment of the shrub species revealed that among the selected villages the highest number of shrub species were in village Parlog, whereas the lowest in Khaira. Further, village Parlog have the highest shrub density, whereas lowest in Khaira. A similar study regarding the phytosociological assessment of species has also been carried out wherein it was reported that the shrub density of sub-tropical areas ranges between 0.2-500 ind/ha. (Kanwal and Joshi 2015, Dhiman et al 2020) However, the importance value index of tree species indicated that *Lantana camara, Adhatoda vasica* and *Murraya koenigii, Lantana camara-Adhatoda vasica* and *Cynodon dactylon, Cenchrus ciliaris* and *Saccharum spontaneum* were the most dominant communities recorded from village Parlog, Bathora and Khaira, respectively. Thus, it can be concluded from the present investigation that greater loss of shrubs was associated with village Parlog and *Lantana camara* and

Table 3. Phytosociological description of tree species in Parlog village

Trees	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Ailanthus excelsa	4.67	20.00	0.140	2.50	7.33	7.69	2.71	17.73
Bombax ceiba	3.33	16.67	0.271	1.78	5.09	6.54	5.39	17.02
Dalbergia sissoo	4.33	23.33	0.504	1.94	7.03	9.13	3.81	19.97
Eriobotrya japonica	2.67	10.00	0.214	0.89	3.76	3.45	2.77	9.97
Ficus auriculata	3.33	20.00	0.042	1.89	5.77	7.80	1.09	14.66
Ficus benghalensis	2.00	6.67	0.021	0.67	2.84	2.48	0.30	5.63
Ficus palmata	8.33	26.67	0.253	2.11	13.06	10.28	4.86	28.20
Grewia optiva	13.00	46.67	2.363	2.77	20.62	17.97	41.51	80.10
Leucaena leucocephala	11.33	33.33	1.283	3.47	18.47	13.00	30.34	61.82
Mallotus philippensis	2.67	13.33	0.033	2.17	4.57	5.02	1.11	10.71
Phoenix sylvestris	0.33	3.33	0.001	0.33	0.47	1.15	0.00	1.62
Phyllanthus emblica	0.67	6.67	0.001	0.67	0.97	2.48	0.01	3.46
Syzygium cumini	2.00	13.33	0.047	1.00	3.32	5.44	1.03	9.80
Toona ciliata	4.00	20.00	0.246	2.28	6.70	7.56	5.06	19.32
Total	62.67	18.57	5.419	1.75	100.0	100.00	100.00	300.00

Table 4. Phytosociological description of shrub species in Khaira village

| Shrubs	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Agave americana	3.00	20.00	0.012	1.50	2.25	12.56	0.14	14.95
Berberis lycium	2.67	16.67	0.003	1.67	1.98	10.17	0.04	12.19
Berberis vulgaris	6.67	6.67	0.083	3.33	4.27	3.03	0.85	8.15
Carissa carandas	5.33	20.00	0.033	1.78	4.00	11.69	0.32	16.01
Lantana camara	78.33	50.00	7.443	16.03	58.73	30.52	77.96	167.21
Murraya koenigii	23.67	36.67	1.336	6.13	17.51	21.86	12.97	52.35
Zanthoxylum armatum	15.00	16.67	0.529	5.56	11.25	10.17	7.72	29.14
Total	134.67	23.81	9.439	5.14	100.00	100.00	100.00	300.00

Adhatoda vasica were the most affected community recorded from the study area.

A. Gravia optiva

B. Syzygium cumini
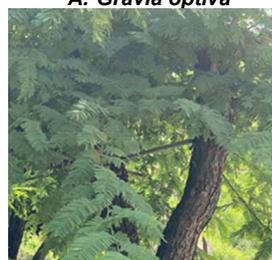
C. Acacia catechu

D. Phyllanthus emblica

E. Leucaena leucocephala

F. Ficus auriculata

Fig. 2. Tree species recorded in the study area

Phytosociological description of herbaceous species

The survey of herbaceous species was also conducted in selected villages of dam catchment. The vegetation analysis of herbaceous species of Khaira village revealed that 12 herbaceous species. Out of the total species *Cynodon dactylon* has highest (190.25 ind/ha) density whereas the lowest (0.83 ind/ha) was for *Bambusa bambos* (Table 7). The IVI value revealed that mixed associated community of *Cynodon dactylon*, *Cenchrus ciliaris* and *Saccharum spontaneum* was with the IVI value of 90.84, 44.84, 44.49, respectively. The total of 18 species were recorded in Bathora village, among different species, the highest density of 74.50 ind/ha was for *Parthenium hysterophorus* whereas

A. Adhatoda vasica

B. Agave spp.

C. Punica granatum

D. Carissa carandus

Fig. 3. Shrub species recorded in the study area

Table 5. Phytosociological description of shrub species in Bathora village

Shrubs	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Adhatoda vasica	38.67	23.33	2.209	17.56	22.85	11.82	35.58	70.24
Asparagus racemosus	3.67	6.67	0.001	3.67	2.21	3.41	0.03	5.65
Berberis vulgaris	14.33	13.33	0.135	7.17	8.97	6.07	4.81	19.86
Agave cantala	0.67	3.33	0.001	0.67	0.45	1.45	0.03	1.93
Dodonaea viscosa	4.33	6.67	0.004	2.17	2.37	3.92	0.04	6.33
Euphorbia royleana	9.33	20.00	0.106	2.75	5.55	9.25	3.07	17.87
Lantana camara	41.67	40.00	1.259	10.36	24.35	20.13	26.71	71.18
Murraya koenigii	28.00	40.00	0.839	7.00	16.78	19.99	21.43	58.20
Opuntia monacantha	0.67	3.33	0.001	0.67	0.45	1.45	0.04	1.93
Punica granatum	0.67	6.67	0.003	0.33	0.45	2.90	0.14	3.48
Vitex negundo	7.33	10.00	0.023	2.44	4.24	4.76	0.66	9.66
Zanthoxylum armatum	18.00	23.33	0.447	7.67	10.68	11.96	7.07	29.71
Ziziphus mauritiana	1.00	6.67	0.010	0.50	0.67	2.90	0.38	3.95
Total	168.33	15.64	5.038	4.84	100.00	100.00	100.00	300.00

lowest (0.83 ind/ha) for *Bambusa bambos.* The IVI value rrevealed *Parthenium hysterophorus* and *Saccharum spontaneum* were most dominant species respectively (Table 8). In village Parlog total of 14 species of herbs were observed and the highest density (79.92 ind/ha) was observed for *Cynodon dactylon* whereas the lowest density (4.50 ind/ha) was for *Mentha sylvestris*. The IVI value was higher for *Parthenium hysterophorus*, *Cynodon dactylon* and *Saccharum spontaneum* in Parlog (Table 9) (Fig. 4).

The phytosociological assessment of the herbaceous species revealed that highest number of herbaceous species

was in village Bathora, whereas lowest in Khaira. Further, village Khaira have the highest herb density, whereas the lowest in Bathora. Similar study regarding the phytosociological assessment of also reported that the herb density of sub-tropical area ranges between 2-500 ind/ha (Sharma and Samant 2013, Shah and Mir 2019, Singh et al 2019, Singh and Devi 2020). However, the importance value index of herb species revealed that *Cynodon dactylon-Cenchrus ciliaris* and *Saccharum spontaneum-Parthenium hysterophorus* and *Saccharum spontaneum-Parthenium hysterophorus-Cynodon dactylon*, and *Saccharum*

Table 6. Phytosociological description of shrub species in Khaira village

Shrubs	D (ind/ha)	F (%)	TBA (m^2/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Adhatoda vasica	31.33	30.00	3.858	10.47	20.00	15.23	35.33	70.57
Asparagus racemosus	7.00	13.33	0.037	1.75	5.31	6.41	2.53	14.25
Berberis vulgaris	9.00	6.67	0.161	4.50	1.98	3.85	3.16	8.98
Desmodium elegans	10.33	6.67	0.032	5.17	2.59	5.13	0.71	8.43
Ipomoea carnea	2.67	3.33	0.001	2.67	0.99	1.28	0.03	2.30
Lantana camara	54.00	53.33	6.715	9.22	27.64	22.06	45.78	95.48
Lonicera angustifolia	13.00	3.33	0.125	13.00	3.83	2.56	3.29	9.68
Murraya koenigii	15.67	30.00	0.313	5.93	13.89	13.76	4.56	32.22
Punica granatum	0.67	6.67	0.003	0.33	0.54	3.70	0.03	4.27
Rubus ellipticus	12.00	10.00	0.047	4.00	9.68	5.56	0.42	15.65
Vitex negundo	19.67	13.33	0.089	9.83	8.86	6.07	2.30	17.23
Woodfordia fruticose	6.67	13.33	0.004	3.33	2.91	6.27	0.13	9.30
Zanthoxylum armatum	5.33	10.00	0.098	1.78	0.99	2.56	1.62	5.17
Ziziphus mauritiana	1.00	10.00	0.013	0.33	0.81	5.56	0.11	6.48
Total	188.33	15.00	11.496	5.17	100.00	100.00	100.00	300.00

Table 7. Phytosociological description of herbaceous species in Khaira village

Herbs	D (ind/ha)	F (%)	TBA (m^2/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Adhatoda zeylinica	17.67	28.33	0.091	6.33	3.66	13.66	3.24	20.55
Bambusa bambos	0.83	3.33	0.001	0.83	0.22	1.80	0.05	2.07
Cannabis sativa	34.00	15.00	0.354	14.83	5.55	6.43	6.42	18.40
Cenchrus ciliaris	81.33	21.67	1.242	41.17	15.52	9.74	19.57	44.84
Cynodon dactylon	190.25	35.00	5.736	59.33	33.11	14.13	43.61	90.84
Martynia annua	11.42	21.67	0.060	4.50	2.03	7.47	1.11	10.60
Oxalis corniculata	17.50	11.67	0.021	5.00	4.53	6.31	0.86	11.70
Parthenium hysterophorus	8.75	5.00	0.078	5.83	2.26	2.70	3.18	8.15
Rumex hastatus	7.75	5.00	0.023	5.17	2.01	3.57	1.01	6.60
Saccharum spontaneum	106.08	25.00	0.766	40.33	18.89	11.28	14.33	44.49
Sida cordata	24.50	10.00	0.041	16.33	6.35	6.27	1.76	14.39
Tinospora cordifolia	9.17	16.67	0.033	1.83	1.10	4.76	0.16	6.02
Urtica dioica	25.17	26.67	0.152	9.50	4.76	11.88	4.70	21.35
Total	534.42	17.31	8.598	16.23	100.00	100.00	100.00	300.0

spontaneum were the most dominant communities recorded from village Khaira, Bathora and Parlog. Thuis indicate greater loss of herbaceous layer was associated with village Bathora and *Parthenium hysterophorus* were the most affected species.

Status of species diversity and concentration dominance of different plant species

The shannon diversity index (h) for the tree species was highest in Parlog village (2.2) whereas the lowest (1.66) was in village Khaira. However, the highest shrub diversity (1.81)

Table 8. Phytosociological description of herb species in Bathora village

Herbs	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Achyranthes bidentata	14.50	5.00	0.038	9.67	4.72	3.23	0.83	8.78
Adhatoda zeylinica	8.83	6.67	0.023	8.83	2.60	3.82	0.47	6.89
Bambusa bambos	0.83	3.33	0.001	0.83	0.22	1.67	0.01	1.90
Cenchrus ciliaris	50.08	18.33	0.582	28.17	15.54	10.52	10.94	37.00
Cynodon dactylon	20.33	3.33	0.089	20.33	5.29	1.67	1.50	8.46
Dactyloctenium aegyptium	12.83	11.67	0.157	3.67	3.34	5.83	2.66	11.83
Dicanthium annulatum	6.67	8.33	0.027	2.67	2.17	5.38	0.59	8.14
Erigeron annuus	11.33	15.00	0.016	7.67	3.54	8.88	0.34	12.76
Eupatorium adenophorum	2.50	8.33	0.001	1.00	1.05	5.21	0.03	6.16
Martynia annua	5.00	8.33	0.005	4.17	1.46	4.65	0.10	6.22
Mellisa officinalis	6.17	3.33	0.007	6.17	2.26	2.08	0.17	4.51
Mentha sylvestris	3.33	3.33	0.003	3.33	0.87	1.67	0.06	2.59
Mirabilis jalapa	5.50	5.00	0.009	3.67	2.02	3.13	0.22	5.36
Oxalis corniculata	17.50	8.33	0.015	7.00	6.42	5.21	0.36	11.99
Parthenium hysterophorus	74.50	28.33	2.764	26.17	24.03	16.87	60.88	101.78
Saccharum spontaneum	65.67	20.00	1.009	32.83	19.90	11.80	18.72	50.41
Sida cordata	11.08	11.67	0.118	9.50	3.46	6.73	2.03	12.23
Urtica dioica	4.83	3.33	0.005	4.83	1.26	1.67	0.08	3.00
Total	321.50	9.54	4.869	10.03	100.13	100.00	100.00	300.0

Table 9. Phytosociological description of herb species in Parlog village

Herbs	D (ind/ha)	F (%)	TBA (m²/ha)	A	RD (%)	RF (%)	RBA (%)	IVI
Achyranthes bidentata	45.83	23.33	0.366	18.83	13.02	14.10	4.98	32.11
Adhatoda zeylanica	11.00	11.67	0.032	6.33	2.45	6.20	0.34	8.99
Cannabis sativa	8.83	3.33	0.058	8.83	1.57	1.71	0.46	3.74
Cenchrus ciliaris	46.83	13.33	0.688	22.33	9.66	7.05	6.24	22.95
Cynodon dactylon	79.92	11.67	3.164	22.83	14.18	5.98	25.26	45.42
Dactyloctenium aegyptium	9.33	6.67	0.024	4.67	2.59	3.70	0.33	6.62
Erigeron annuus	22.83	18.33	0.085	8.50	7.96	12.32	1.51	21.79
Martynia annua	5.33	10.00	0.004	5.33	1.61	6.13	0.05	7.80
Mentha sylvestris	4.50	3.33	0.007	4.50	0.80	1.71	0.06	2.56
Oxalis corniculata	8.75	5.00	0.007	5.83	1.55	2.56	0.06	4.17
Parthenium hysterophorus	51.50	21.67	3.017	16.00	18.48	14.53	48.69	81.70
Saccharum spontaneum	55.50	20.00	0.674	28.00	15.71	11.82	8.37	35.91
Synedrella nodiflora	27.42	15.00	0.186	17.67	9.57	9.61	3.53	22.71
Urtica dioica	4.75	5.00	0.015	3.17	0.84	2.56	0.12	3.53
Total	382.33	12.02	8.327	12.35	100.00	100.00	100.00	300

Table 10. Status of species diversity and concentration dominance of different plant species in the study area

Villages	Species diversity (h)			Concentration of dominance (cd)		
	Trees	Shrubs	Herbs	Trees	Shrubs	Herbs
Khaira	1.66	1.13	1.83	0.20	0.41	0.19
Bathora	1.79	1.81	1.98	0.21	0.18	0.16
Parlog	2.2	1.63	1.81	0.13	0.26	0.2
Mean	1.88	1.52	1.87	0.18	0.29	0.18

A. *Mirabilis jalapa*

B. *Parthenium hysterophorous*   **C.** *Synedrella nodiflora*

Fig. 4. Herbaceous species recorded in the study area

was in Bathora village whereas lowest (1.13) in Khaira. For the herb layer, the highest (1.98) diversity was in Bathora whereas the lowest (1.81) in Parlog. The highest value of simpson's index (0.21) for the trees was in Bathora whereas the lowest (0.13) was in Parlog. Simpson's value for shrubs was highest (0.41) in village Khaira whereas lowest (0.18) in Bathora. For the herb layer, Parlog has the highest value (0.20) whereas the lowest Simpson index (0.16) was in Bathora (Table 10). The diversity was highest for trees whereas it was lowest for shrubs. Similarly, the level of dominance was higher for shrubs and lowest for trees and herbs. Similar study regarding the phytosociological assessment of species was carried out, wherein reported that the tree species diversity ranged between 0.9-2.59, shrub species diversity ranged between 1.0–4.0 and the herb species diversity ranged between 0.9- 3.0. Further the dominance ranged between 0.13-0.40 for trees, 0.08-0.41 for shrubs and 0.03-0.40 for herbs (Mohapatra et al 2020, Dhiman et al 2020, Shah and Mir 2019, Singh and Devi 2020).

CONCLUSION

The vegetational analysis of the proposed Sunni hydroelectric project area revealed that overall, 20 trees, 21 shrubs and 21 herbaceous species were recorded from the study area. The area with the highest floristic diversity and density will have a greater risk of being affected after the dam construction. This study would be considered a supportive tool for compensatory afforestation planning as well as baseline for any further research in this area.

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Production Potential, Profitability and Nitrogen use Efficiency of Forage Pearl Millet Varieties

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Abstract: Field experiment was conducted to study the production potential, profitability and nitrogen use efficiency of forage pearl millet varieties with nitrogen doses. The experiment comprised of four forage pearl millet varieties (TSFB 15-4, TSFB 15-8, Moti bajra and BAIF bajra-1) at two N levels (80 and 120 kg N/ha) and the eight treatment combinations were tested.BAIF bajra-1 with 120 kg N/ha recorded the maximum green forage yield, dry matter and crude protein yield, gross and net return and B:C ratio. This treatment also exhibited markedly higher nitrogen uptake but markedly higher partial factor productivity of nitrogen fertilizer was recorded in BAIF bajra-1 with 80 kg N/ha. Hence, BAIF bajra-1 with application of 120 kg N/ha was the most promising treatment for achieving higher nitrogen uptake, dry matter yield and crude protein yield.

Keywords: Production potential, Profitability, Nitrogen use efficiency, Forage pearl millet, N levels

Due to ever increasing livestock population in India, there is a tremendous pressure on feed and fodder resources. Parmar and Misra (2020) indicate there was a deficit of 26%green fodder in the country during 2015 which is expected to increase up to 40% by 2025. As forage crops are already facing severe competition from other cash crops for occupying arable land (Choudhary and Prabhu 2014), efforts for enhancement of production and productivity of forage crops is of outmost importance for sustaining the livestock production and profit margins of dairy farmers (Nanda et al 2021).Pearl millet (*Pennisetum glaucum* L.) ranks sixth among the cereal crops of the world on the basis of area under cultivation and is popular among farmers for providing food and fodder (Pujarula et al 2021). It can be grown successfully in both rainfed and irrigated condition (Ayubet al 2009) and is becoming popular among farming community of Bihar due to its short duration, quick regeneration capacity and ability to provide superior and palatable green fodder in summer and rainy season. Nitrogen one of the key nutrients for crop production (Nanda and Nilanjaya 2022) which influences vegetative growth and herbage quality (Bramhaiah et al 2018). Previous reports indicated that enhancing N application improves yield and quality of pearl millet (Shekara et al 2019,Shekaraet al2021 and Nanda and Nilanjaya 2022) but decreases nitrogen use efficiency (Rostamza et al 2011,Shekara et al 2019, Shekara et al 2021 and Nanda and Nilanjaya 2022). Recently, two varieties such as TSFB 15-4 and TSFB 15-8 with higher production potential have been released. Hence, nitrogen management

in these forage pearl millet varieties could further improve the productivity and quality, profitability and nitrogen use efficiency for sustaining livestock production. Current investigation was carried out to assess the production potential, profitability and nitrogen use efficiency of forage pearl millet varieties with nitrogen doses.

MATERIAL AND METHODS

Experimental site: The present experiment was conducted at RPCAU, Pusa, Samastipur, Bihar during *Kharif* season, 2020.Geographically, the site falls under the sub-tropical zone of Indo-Gangetic plains and is situated at the bank of river *Budhi Gandak*. It is located on $25^0 98^' $N latitude, $85^0 68^'$E longitude and at an elevation of 63.9 meters above MSL. Pusa, Samastipur experiences subtropical humid weather and receives an annual average rainfall of 1200 mm of which 941 mm (about 70 percent rainfall) is received during July and September. Usually monsoon arrives in the third week of June which remains till end of September or sometimes till first week of October. The winter months are very cool whereas the summer months are hot, dry and humid. Total rain fall during crop growing period was 1026.5 mm. The soil was silty clay loamin nature with pH of 8.52. The soil was low in organic carbon (0.46%), available nitrogen (199.1 kg/ha) high in available P (35.6 kg/ha)and low in available K (86.2 kg/ha).

Experimental design: Four forage pearl millet varieties were evaluated in the experiment (TSFB 15-4, TSFB 15-8, Moti bajra and BAIF bajra-1) at two N levels (80 and 120 kg

N/ha) and these eight treatment combinations representing eight treatments (Table 1) were evaluated in randomized block design using three replications with individual plot size of 12 m² (4m × 3m) plot.The crop was sown on July 2, 2020 at a row spacing of 30 cm using a seed rate of 10 kg/ha. Recommended dose of 30 kg each of P and K was applied at the time of sowing. Application of N was done as per the treatments *i.e.* 80 or 120 kg N/ha. Of the total quantity of fertilizer N, 40% was applied as basal, 30% was applied after 1st cut and rest 30% was applied after 2st cut. Regarding harvest of green fodder, first cut was taken at 50 days after sowing (DAS), second cut was taken at 30 days after 1st cut and the 3rd cut was taken at 50% flowering. Other cultural operations were done as per recommended package of practices. The sources for nitrogen, phosphorus and potassium were urea, SSP and MOP, respectively.

Observations and method of analysis: At each harvest, observation on plant height (cm), number of tillers/m row length (TMRL) and leaf: stem ratio (LSR) (dry weight basis) was taken. Green forage yield (GFY) of the plot was recorded and converted to t/ha. A representative sample of 500g of green fodder was taken from each plot and dry matter (DM) content was determined by placing a hot air oven at 70 ± 2°C temperature till constant weight was achieved. Dry matter yield (DMY) was calculated by multiplying GFY with DM content. Nitrogen (N) content of the dry matter was determined using modified Kjeldahl method (AOAC 1955) and it was multiplied by the DMY to get N uptake. The N content in dry matter was multiplied by a factor 6.25 to get crude protein (CP) content. CP content (%) was multiplied by DMY to get crude protein yield (CPY).The partial factor productivity of N fertilizer (PFPN) was calculated as per Singh et al (2021) in terms of GFY and DMY as follows

PFPN (kg DMY/kg N applied) = DMY/AFNA

Where DMY is DMY in fertilized plot (kg/ha)

AFNA is the amount of fertilizer nitrogen applied (kg/ha)

N fertilizer use efficiency (NFUE) was calculated as per Hou et al (2021) as follows

NFUE (kg CPY/kg N applied) = CPY (kg/ha)/AFNA (kg/ha).

Nitrogen utilization efficiency (NutE) was worked out as per Rostamza et al (2011)

NutE (kg DM/kg N uptake) = DMY/NU

Where DMY is the dry matter yield (kg/ha) of the plot and NU is the nitrogen uptake (kg/ha) of that plot.

The economics of forage pearl millet was calculated with prevailing market price of the inputs and the output.Data were analyzed as per Analysis of Variance for randomized block design using online statistical package OPSTAT (Sheoran et al 1998).

RESULTS AND DISCUSSION

Yield attributes: Different treatments caused significant variation in plant height for first cut (Table 1). The highest plant height was in BAIF bajra-1 with 120 kg N/ha (184.0 cm) which was comparable with other treatments except TSFB 15-4 at 80 and 120 kg N/ha (Table 1). For second and third cut, the highest plant height was with TSFB 15-4 with 120 kg N/ha (166.9 cm) and TSFB 15-4 with 120 kg N/ha (141.9 cm), respectively. Different treatments had significant effect on number of tillers per meter row length (TMRL) for first and third cut (Table 1). Significantly higher TMRL was recorded in BAIF bajra-1 with 120 kg N/ha at first cut (47.0) which was significantly superior to rest of the treatments. The TMRLat second cut was withBAIF bajra-1 with 120 kg N/ha (45.0). Application of 120 kg N/ha recorded the highest number TMRL (39.2) which was comparable with rest of the treatments except TSFB 15-4 at 80 and 120 kg N/ha. LSR showed significant variation at each cut and Moti bajra with 120 kg N/ha recorded the highest value of LSR at each cut

Table 1. Plant height, number of tillers and leaf: stem ratio of forage pearl millet varieties with varied nitrogen doses

Treatments	Plant height (cm)			Number of tillers/m row length			Leaf: stem ratio		
	First cut	Second cut	Third cut	First cut	Second cut	Third cut	First cut	Second cut	Third cut
T₁-TSFB 15-4 with 80 kg N/ha	151.3	164.5	128.6	29.0	34.1	27.2	0.40	0.46	0.39
T₂-TSFB 15-4 with 120 kg N/ha	153.6	166.9	130.8	33.0	36.1	28.3	0.43	0.48	0.39
T₃-TSFB 15-8 with 80 kg N/ha	176.6	156.2	140.9	36.0	37.8	35.3	0.42	0.38	0.37
T₄-TSFB 15-8 with 120 kg N/ha	178.5	158.3	141.9	42.0	39.6	36.2	0.45	0.41	0.38
T₅-Moti bajra with 80 kg N/ha	171.4	151.1	136.4	33.0	36.4	34.2	0.54	0.51	0.49
T₆-Moti bajra with 120 kg N/ha	174.6	153.8	137.8	38.0	37.0	34.8	0.57	0.54	0.50
T₇-BAIF bajra-1 with 80 kg N/ha	181.3	159.8	133.7	40.0	42.0	38.6	0.46	0.44	0.45
T₈-BAIF bajra-1 with 120 kg N/ha	184.0	162.4	132.7	47.0	45.0	39.2	0.48	0.47	0.49
CD (p<0.05)	14.8	NS	NS	3.4	NS	6.5	0.09	0.03	0.05

(0.57, 0.54 and 0.50, respectively) which was statistically similar with Moti bajra with 80 kg N/ha at each cut and BAIF bajra-1 with 120 kg N/ha at first and third cut and BAIF bajra-1 with 80 kg N/ha at third cut (0.45).Nitrogen plays important role in cell division and elongation than might have resulted in higher plant height, TMRL and LSR. Ayub et al (2009) also reported that plant height increased significantly up to application of 180 kg N/ha. Similarly, significant effect of N on plant height and LSR of pearl millet varieties for first, second and third cut has been reported by Aboelgoud and Ragab (2021).

Yield: Different treatments caused significant variation in GFY and DMY for first and second cut and total GFY and DMY (Table 2). BAIF bajra-1 with 120 kg N/ha gave the highest GFY at first cut (28.6 t/ha) which was at par with BAIF bajra-1 with 80 kg N/ha. For second cut, TSFB 15-4 with 120 kg N/ha recorded the highest GFY (21.2 t/ha) which was comparable with BAIF bajra-1 with 120 kg N/ha and TSFB 15-4 with 80 kg N/ha. However, Moti bajra with 120 kg N/ha produced the highest GFY at third cut. Total GFY was the highest with BAIF bajra-1 with 120 kg N/ha (59.0 t/ha) which was comparable with BAIF bajra-1 with 80 kg N/ha. BAIF bajra-1 with 120 kg N/ha produced significantly higher DMY for first and second cut which was at par with TSFB 15-4 with 120 kg N/ha for DMY of second cut. For third cut both TSFB 15-8 and Moti bajra with 120 kg N/ha produced the highest DMY (2.1 t/ha). However, total DMY was significantly higher with BAIF bajra-1 with 120 kg N/ha (12.0 t/ha). Shekara et al (2020) also observed that multi-cut forage pearl millet genotypes responded significantly up to 120 kg N/ha for GFY and DMY. Higher DMY with 120 kg N/ha was due to increase in DM content (Shekara et al 2020). Our results are in line with the findings of Ayub et al (2009) that GFY and DMYof pearl millet markedly increased up to application of 180 kg N/ha. Increase in N dose (from 80 to 120 kg N/ha) was

reflected in on growth attributes *i.e.* plant heightand TMRL and resulted in higher green forage and dry matter yield of pearl millet varieties. Similar trend was observed by Ibrahim et al (2014) and Aboelgoud and Ragab (2021).

Fodder quality: Different treatments caused marked variation in crude protein (CP) content and its yield except CP content of third cut (Table 3). CP content for first cut was highest withTSFB 15-8 with 120 kg N/ha (8.73%) which was comparable with BAIF bajra-1 with 120 kg N/haand TSFB 15-8 with 80 kg N/ha. BAIF bajra-1 with 120 kg N/ha produced the highest CP content at second cut (7.45%) which was at par with BAIF bajra-1 with 80 kg N/ha, TSFB 15-8 with 120 kg N/ha and TSFB 15-8 with 80 kg N/ha. TSFB 15-8 with 120 kg N/ha resulted in the highest CP content of third cut). Ayubet al (2009) observed that CP content of pearl millet increased significantly up to application of 180 kg N/ha. Similarly, Aboelgoud and Ragab (2021) observed that increasing N levels brought significant increase in CP contents of first, second and third cut of forage pearl millet varieties. CPY of first and second cut was the highest with BAIF bajra-1 with 120 kg N/ha which was comparable with TSFB 15-8 with 120 kg N/ha for first cut and BAIF bajra-1 with 80 kg N/ha (0.27 t/ha) and TSFB 15-4 with 120 kg N/ha (0.26 t/ha) for second cut. Regarding CPY of third cut, TSFB 15-8 with 80 and 120 kg N/ha recorded the highest value (0.18 t/ha) and were comparable with all other treatments except for TSFB 15-4 with 80 kg N/ha and 120 kg N/ha. However, total CPY was significantly higher with BAIF bajra-1 with 120 kg N/ha (0.97 t/ha). Higher CPY with 120 kg N/ha than application of 80 kg N/ha with multi-cut genotypes of forage pearl millet was noted by Shekara et al (2020) which was due to higher CP content and dry matter yield.

Nitrogen uptake: Different treatments caused significant variation in nitrogen uptake for first, second and third cut as well as total nitrogen uptake (Table 4). The highest N uptake

Table 2. Green forage and dry matter yield of forage pearl millet varieties with varied nitrogen doses

Treatments	Green forage yield (t/ha)				Dry matter yield (t/ha)			
	First cut	Second cut	Third cut	Total	First cut	Second cut	Third cut	Total
T_1	17.9	20.1	9.0	46.9	3.3	3.6	1.7	8.5
T_2	19.8	21.2	9.3	50.2	3.8	4.0	1.7	9.5
T_3	23.6	16.2	10.5	50.2	4.5	3.1	2.1	9.7
T_4	25.8	16.9	10.7	53.3	5.2	3.4	2.1	10.7
T_5	23.5	15.1	10.5	49.1	4.5	2.8	2.0	9.3
T_6	25.6	16.3	10.8	52.7	5.1	3.2	2.1	10.5
T_7	27.1	19.1	9.9	56.1	5.2	3.6	2.0	10.8
T_8	28.6	20.2	10.2	59.0	5.8	4.1	2.1	12.0
LSD (p=0.05)	2.8	1.7	NS	3.2	0.6	0.3	NS	0.9

See Table 1 for treatment details

for first and second was observed with TSFB 15-8 with 120 kg N/ha (79.7 and 48.4 kg/ha, respectively) which was comparable with TSFB 15-8 with 120 kg N/ha for first cut and BAIF bajra-1 with 80 kg N/ha for second cut. TSFB 15-8 with 120 kg N/ha recorded the highest N uptake for third cut (29.0 kg/ha) which was comparable with rest of the treatments except TSFB 15-4 with 80 kg N/ha and 120 kg N/ha. However, total N uptake was significantly higher with BAIF bajra-1 with 120 kg N/ha (155.9 kg/ha). Higher N uptake of forage pearl millet varieties with 120 kg N/ha might be due to higher availability in soil coupled with better absorption and utilization in crop.

Nitrogen use efficiency: Different treatments caused significant variation in nitrogen use efficiency (NUE) indices (PFPN, NFUE and NutE) (Table 5). NUE indices decreased with increase in N application from 80 to 120 kg N/ha. PFPN, NFUE and NutE varied from 79.0 to 135.1 kg DMY/kg N applied, 5.8 to 10.7 kg CPY/kg N applied, 76.0 to 89.3 DMY/kg N uptake, respectively among the treatments. The

highest PFPN and NFUE was with BAIF bajra-1 with 80 kg N/ha which was statistically similar with TSFB 15-8 with 80 kg N/ha (9.7 kg CPY/kg N applied) for NFUE. However, the

Table 4. Nitrogen uptake by forage pearl millet varieties with varied nitrogen doses

Treatments	N uptake (kg/ha)			
	First cut	Second cut	Third cut	Total
T_1	39.0	38.2	20.4	97.6
T_2	47.7	42.1	21.5	111.3
T_3	60.5	35.1	28.5	124.1
T_4	73.5	39.5	29.0	142.0
T_5	53.7	30.3	25.3	109.3
T_6	65.6	35.2	26.6	127.4
T_7	67.6	43.2	26.2	136.9
T_8	79.7	48.4	27.8	155.9
CD (p<0.05)	8.5	5.7	5.0	11.9

See Table 1 for treatment details

Table 3. Crude protein content and yield of forage pearl millet varieties with varied nitrogen doses

Treatments	Crude protein (%)				Crude protein yield (t/ha)			
	First cut	Second cut	Third cut	Total	First cut	Second cut	Third cut	Total
T_1	7.40	6.52	7.74	0.24	0.24	0.13	0.61	
T_2	7.81	6.60	7.80	0.30	0.26	0.13	0.70	
T_3	8.30	7.13	8.54	0.38	0.22	0.18	0.78	
T_4	8.73	7.29	8.61	0.46	0.25	0.18	0.89	
T_5	7.53	6.70	7.81	0.34	0.19	0.16	0.68	
T_6	7.91	6.82	7.86	0.41	0.22	0.17	0.80	
T_7	8.02	7.40	8.30	0.42	0.27	0.16	0.86	
T_8	8.46	7.45	8.37	0.50	0.30	0.17	0.97	
CD (p<0.05)	0.44	0.62	NS	0.05	0.04	0.03	0.07	

See Table 1 for treatment details

Table 5. Nitrogen use efficiency and production economics of forage pearl millet varieties with varied nitrogen doses

Treatments	Nitrogen use efficiency			Economics		
	PFPN (kg/kg)	NFUE (kg/kg)	NutE (kg/kg)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio
T_1	106.4	7.6	89.3	70382	37284	2.13
T_2	79.0	5.8	86.2	75347	41769	2.24
T_3	121.0	9.7	78.8	75332	42234	2.28
T_4	89.3	7.4	76.0	79935	46357	2.38
T_5	116.3	8.5	85.5	73608	40510	2.22
T_6	87.2	6.6	82.9	79026	45448	2.35
T_7	135.1	10.7	79.9	84149	51051	2.54
T_8	99.7	8.1	77.2	88490	54912	2.64
CD (p<0.05)	10.6	1.0	4.1	4764	4764	0.14

See Table 1 for treatment details

highest NutE was recorded with TSFB 15-4 with 80 kg N/ha (89.3kg DMY/kg N uptake) which was comparable with TSFB 15-4 with 120 kg N/ha (86.2 kg DMY/kg N uptake) and Moti bajra with 80 kg N/ha (85.5 kg DMY/kg N uptake). Variation in nitrogen use efficiency exists in forage pearl millet genotypes (Shekara et al 2019, 2021) and multi-cut forage genotypes exhibited lower NUE with 120 kg N/ha than 80 kg N/ha (Shekara et al 2020).

Production economics: Different treatments caused significant variation in profitability indices like gross and net return and B:C ratio (Table 5). The highest gross and net return and B:C ratio was with BAIF bajra-1 with 120 kg N/ha (Rs. 88490/ha, Rs. 54912/ha and 2.64, respectively) which was at par with BAIF bajra-1 with 80 kg N/ha. Higher gross and net return and B:C ratio with BAIF bajra-1 with 120 kg N/ha was mainly due to higher GFY recorded in this treatment. Shekara et al (2020) also reported that applying 120 kg N/ha registered higher gross and net return and B:C ratio compared to 80 kg N/ha in multi-cut fodder pearl millet genotypes.

CONCLUSION

BAIF bajra-1 with application 120 kg N/ha resulted in higher green forage yield, dry matter yield, crude protein yield and nitrogen uptake and profitability indices such as net return and B:C ratio.

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Effect of Water-Soluble Fertilizers and Plant Growth Promoting Rhizomicrobial Consortia on Nutrient Content, Uptake and Soil Chemical Properties in Blackgram

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Abstract: The field experiment was conducted with an objective to study the effect of water-soluble fertilizers and PGPR on yield and nutrient uptake of blackgram under rainfed condition during *Kharif*-2019 at University of Agricultural and Horticultural Sciences, Shivamogga. Initial soil nutrient status showed that available nitrogen (242.22 kg ha^{-1}), high phosphorus (75.08 kg P_2O_5 ha^{-1}) and medium potassium (135.63 kg K_2O ha^{-1}) was low. There were thirteen treatments consisting of different combinations of 19:19:19 and monopotassium phosphate (0:52:34) with or without liquid plant growth promoting rhizomicrobial consortia application. Treatments significantly influenced by foliar fertilization and plant growth promoting rhizomicrobial consortia application. The foliar application of 19:19:19 (N: P: K) and monopotassium phosphate (0:52:34) @ 1 per cent each at 30 and 45 days after sowing + PGPR along with a package of practice treatment recorded significantly higher nitrogen, phosphorous, potassium content (3.52, 0.42 and 2.10 %, respectively in seed) and uptake (69.49, 9.26 and 64.08 kg ha^{-1}, respectively) and also observed higher soil available N, P and K at 60 DAS and at harvest stage, respectively in the same treatment over package of practice.

Keywords: Blackgram, Soil fertility, Nutrient uptake, PGPR, Water soluble fertilizers

Blackgram (*Vigna mungo* L.) is a well-known leguminous crop in Asia and is adapted to a wide range of agro-climatic conditions because of its morphological parameters perfectly suited for intercropping and sole cropping systems. It is extensively grown as a grain legume for food and nutritional security (Anonymous 2019). In India, black gram contributes about 13 percent of the total pulse area and 10 percent of their total production and it was cultivated over an area of about 4.6 M ha with a production of 3.56 Mt. with a productivity of 654 kg ha^{-1} and in Karnataka, is cultivated over an area of 1.38 lakh ha with a production of 0.47 lakh tonnes (Anonymous 2018). Black gram is a highly priced pulse having a wide gap between the potential yield and actual yield. Low productivity of blackgram is due to marginal and poor soil fertility and imbalanced nutrition under rainfed condition (Thriveni et al 2023). Black gram is indeterminate flowering and fruiting habit and there was a continuous competition for available assimilates between vegetative and reproductive sinks during critical stages. The availability of nitrogen, phosphorus and potassium are often limiting for proper plant growth and productivity. Soil application of nutrients was often not sufficient to meet the nutrient demand of the crops because majority of the soil applied nutrients are lost or fixed. Foliar

application of nutrients was considered an important method of fertilization in rainfed situations since the foliar application of nutrients easily penetrates the leaf cuticle or stomata and enters the cells facilitating easy and rapid utilization and translocation of nutrients from source to sink increases the nutrient content in plant parts (Ramesh et al 2020). Foliar application of fertilizers offers several advantages over traditional soil fertilization methods, effectively circumventing many of the drawbacks associated with soil-based approaches and allowing for rapid absorption and utilization (Kaushal et al 2014). The nutritional management is imperative to ensure better crop production on low fertile soils. PGPR is group of bacteria that colonize the rhizosphere that enhances plant growth and metabolism through different mechanisms. It includes enhanced fixation, mineralization and solubilization of nutrients for easy uptake and assimilation, production of plant growth regulators, siderophore production, as biocontrol agent against plant pathogens (Vejan et al 2016). PGPR application improves soil fertility by encouraging multiplication of beneficial rhizosphere bacteria (Babu et al 2023). The present research aims to determine the effect of water-soluble fertilizers and PGPR on the NPK content and uptake by blackgram and soil nutrient status.

MATERIAL AND METHODS

Field experiment was conducted during the *kharif* season of 2019 at University of Agricultural and Horticultural Sciences, Shivamogga which comes under Southern Transition Zone (Zone-7) of Karnataka. The geographical reference point of the experimental site was 13° 58' to 14° 1' North latitude and 75° 34' to 75° 42' East longitude and at an altitude of 650 m above the mean sea level. The soil was sandy loam in texture, slightly acidic pH (6.19) and normal in electrical conductivity (0.70 dS m^{-1}), low organic carbon (0.46%) , low in available nitrogen (242.22 kg ha^{-1}), high in phosphorus (75.08 kg P$_2$O$_5$ ha^{-1}) and medium in potassium status (135.63 kg K$_2$O ha^{-1}). During the cropping period, the total actual rainfall received was 1088.8 mm. The field experiment was laid out in a randomized complete block design with thirteen treatments and three replications. Treatments consisting of different combinations of water-soluble fertilizers *viz.,* 19:19:19 (N: P: K) and mono potassium phosphate (0:52:34) sprayed at 30 and 45 days after sowing with or without liquid PGPR (*Rhizobium leguminosarum*, *Pseudomonas* sp. and *Bacillus* sp) application along with the package of practice *viz.*, (Table 2). Package of practice of blackgram includes 6.5 t ha^{-1} FYM, 13:25:25 kg NPK ha^{-1} + 4 kg ZnSo$_4$ as basal dose. The variety Rashmi (LBG-625) was used in study and it matures in 85 to 90 days with an average yield ranging from 8 to 9 q ha^{-1}. The plots size was 3.6 and 3.0 m prepared by making bunds of 50 cm width and 30 cm height and treatments were allocated randomly in the plots within the blocks. The recommended dose of fertilizers and farm yard manure @ 7.5 t ha^{-1} was applied at the time of sowing common to all the treatments. Liquid plant growth promoting rhizomicrobial consortia (*Rhizobium leguminosarum*, *Pseudomonas sp.* and *Bacillus sp.*) mixed with farm yard manure at 750 ml ha^{-1} incorporated into soil as per treatments at the time of sowing. The one per cent solution of water-soluble fertilizers 19:19:19 and mono potassium phosphate was used for foliar spraying at 30 and 45 days after sowing as per the treatments.

Table 1. Methods followed in soil analysis

Parameter	Method used
pH	Potentiometric (Jackson 1973
EC	Conductometric (Jackson 1973)
Organic carbon	Wet oxidation (Walkley and Black 1934)
Nitrogen	Alkaline permanganate oxidation (Subbhiah and Asija 1956)
Phosphorous	Spectrometric (0.5 M NaHCO$_3$, pH 8.5, blue colour) (Olsen et al 1954)
Potassium	Flame photometric (Neutral N NH$_4$OAc) (Jackson 1973)

Plant analysis: Seed and plant samples are collected after the harvest of the crop according to treatment. The 500 g of plants and seeds were sampled and each sample was dried under shade and then in a hot air oven at 65°C. Dried samples were grounded 2mm sieve and used for further analysis. These grounded seed and plant samples were used for the estimation of N, P and K content by standard methods and nutrient uptake by the plant is calculated

$$\text{N uptake (kg ha}^{-1}) = \frac{\text{N content (\%)} \times \text{Dry matter production (kg ha}^{-1})}{100}$$

$$\text{P uptake (kg ha}^{-1}) = \frac{\text{P content (\%)} \times \text{Dry matter production (kg ha}^{-1})}{100}$$

$$\text{K uptake (kg ha}^{-1}) = \frac{\text{K content (\%)} \times \text{Dry matter production (kg ha}^{-1})}{100}$$

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Soil analysis: Soil samples were collected from each plot (30 cm depth) at 30, 60 DAS, after harvesting and analyzed for pH, EC, OC and available soil NPK as per the set procedures (Table 1).

Statistical analysis: All the data recorded were processed in Microsoft Excel 2011 and analyzed with ANOVA at 5% level of significance (P ≤ 0.05) (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

NPK content in blackgram: The significantly higher nitrogen content (3.52 and 1.54 %), phosphorus content (0.42 and 0.22 %), potassium content (2.10 and 1.98 %) in seed and haulm was in treatment receiving T$_1$+19:19:19 @ 1 per cent + mono potassium phosphate @ 1 per cent at 30 and 45 DAS + PGPR than all other treatments. This was statistically on par with T$_1$+19:19:19 @ 1 percent + MPP @ 1 percent at 30 DAS + PGPR (Table 2). Foliar application of water-soluble fertilizers s 19:19:19 and mono potassium phosphate facilitates quick penetration through stomata and absorption of nutrients. Increased supply of NPK reflected in greater synthesis of photosynthates and translocation of photosynthates from source to sink, thus improves the nutrient content in seed and nutrient uptake in green gram (Bhavya 2019). PGPR increases the NPK availability in rhizosphere and makes easy absorption by plant roots through fixation, mobilization and solubilization (Vejan et al 2016). The increased nutrient concentration in seed and haulm due to the foliar application of water-soluble fertilizers was also concluded in green gram by Takankhar et al (2018).

NPK uptake by blackgram: Significantly higher nitrogen uptake (40.40, 31.10 and 69.49 kg ha^{-1}), phosphorus uptake (4.82, 4.44 and 9.26 kg ha^{-1}), potassium uptake (24.10, 39.98 and 64.08 kg ha^{-1}) in seed, haulm and total uptake,

respectively was in treatment receiving T_1+19:19:19 @ 1 per cent + mono potassium phosphate @ 1 per cent at 30 and 45 DAS + PGPR than all other treatments. This was statistically on par with T_1+19:19:19 @ 1 per cent + MPP @ 1 per cent at 30 DAS + PGPR. Higher NPK content and higher biomass production attributed to increased NPK uptake by crop. PGPR regulates hormonal and nutritional balance, inducing resistance against plant pathogens and solubilizing nutrients for easy uptake by plants. These results are similar to the findings of Mamathashree et al (2017) and Sharifi et al (2018). Chetana and Math (2018) and Manasa et al (2015) also observed the same trend.

Soil chemical properties: The soil analyses results indicated that there was no substantial changes in soil chemical properties like pH, EC and organic carbon content after harvest of the crop (Table 4). However, higher pH (6.23), OC (4.61 g kg^{-1}) was with T_1+19:19:19 @ 1 per cent + mono potassium phosphate @ 1 per cent at 30 and 45 DAS +

Table 2. Effect of water soluble fertilizers and PGPR on NPK content (%) in blackgram

Treatments details	Seeds			Haulm			Total		
	N	P	K	N	P	K	N	P	K
T_1: Package of practices	3.22	0.36	1.11	1.21	0.15	1.31	3.74	0.51	2.42
T_2: T_1+ 19:19:19 @1% at 30 DAS	3.24	0.38	1.59	1.23	0.17	1.41	4.53	0.55	3.00
T_3: T_2 + PGPR	3.36	0.38	1.58	1.38	0.17	1.53	4.78	0.55	3.11
T_4: T_1 +19:19:19 @1% at 30 and 45 DAS	3.32	0.38	1.70	1.35	0.17	1.51	4.76	0.56	3.21
T_5: T_4+ PGPR	3.37	0.38	1.79	1.38	0.18	1.53	4.83	0.57	3.32
T_6: T_1+ MPP @1% at 30 DAS	3.35	0.39	1.72	1.26	0.17	1.44	4.63	0.56	3.16
T_7: T_6 + PGPR	3.43	0.38	1.75	1.37	0.17	1.55	4.8	0.56	3.30
T_8: T_1+ MPP @1% at 30 and 45 DAS	3.38	0.40	1.75	1.38	0.18	1.66	4.93	0.58	3.41
T_9: T_8 + PGPR	3.42	0.38	1.80	1.38	0.18	1.67	4.74	0.57	3.47
T_{10}: T_1+ 19:19:19@1%+ MPP @1% at 30 DAS	3.40	0.38	1.69	1.34	0.17	1.72	4.72	0.56	3.41
T_{11}: T_{10} + PGPR	3.48	0.40	1.85	1.44	0.19	1.90	4.84	0.60	3.75
T_{12}: T_1+ 19:19:19 @1% + MPP @1% at 30 and 45 DAS	3.41	0.38	1.77	1.31	0.18	1.72	4.55	0.56	3.49
T_{13}: T_{12} + PGPR	3.52	0.42	2.10	1.54	0.22	1.98	5.05	0.64	4.08
CD (p=0.05)	0.06	0.03	0.28	0.11	0.02	0.25	0.64	0.05	0.47

See table 2 for treatment details; Package of practices: 6.5 t ha^{-1} FYM, 13:25:25 kg NPK ha^{-1} + 4 kg ZnSo$_4$

Table 3. Effect of water-soluble fertilizers and PGPR on NPK uptake by blackgram (kg ha^{-1})

Treatments	Seeds			Haulm			Total		
	N	P	K	N	P	K	N	P	K
T_1	25.82	2.89	8.91	19.39	2.07	21.00	45.21	4.99	29.91
T_2	28.17	3.30	13.83	20.17	2.79	23.13	48.35	6.09	36.95
T_3	29.46	3.33	13.85	22.82	2.81	25.30	52.27	6.14	39.15
T_4	29.34	3.36	15.03	23.06	2.90	25.80	52.41	6.26	40.82
T_5	32.54	3.67	17.28	24.39	3.18	27.04	56.93	6.85	44.32
T_6	29.10	3.39	14.94	20.47	2.76	23.39	49.57	6.15	38.33
T_7	30.11	3.34	15.36	22.70	3.15	25.68	52.81	6.49	41.05
T_8	29.97	3.55	15.52	23.67	3.09	28.48	53.64	6.64	43.99
T_9	33.09	3.68	17.41	24.20	3.42	29.29	57.29	7.10	46.70
T_{10}	32.50	3.63	16.15	23.24	2.95	29.82	55.73	6.58	45.98
T_{11}	38.82	4.46	20.63	26.81	3.87	35.37	65.63	8.33	56.01
T_{12}	33.93	3.78	17.61	25.36	3.07	29.36	59.29	6.85	46.97
T_{13}	40.40	4.82	24.10	31.10	4.44	39.98	71.50	9.26	64.08
CD (p=0.05)	4.67	0.51	4.24	4.86	0.61	6.12	9.60	1.16	8.27

See table 2 for treatment details

Table 4. Effect of water-soluble fertilizers and PGPR on soil NPK status at different crop stages

Treatments	pH	EC (dSm^{-1})	OC (g kg^{-1})	Available nitrogen (kg ha^{-1})			Available phosphorous (kg ha^{-1})			Available potassium (kg ha^{-1})		
				30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
T$_1$	6.15	0.73	4.50	248.58	232.32	212.81	78.32	75.3	73.25	147.87	122.2	110.52
T$_2$	6.18	0.70	4.57	251.95	233.87	214.30	79.52	76.32	74.26	148.68	126.25	116.2
T$_3$	6.17	0.69	4.56	253.06	236.00	222.83	80.25	78.68	76.38	150.81	131.87	120.9
T$_4$	6.23	0.70	4.53	255.64	240.87	221.68	80.25	79.98	77.86	149.25	132.18	122.2
T$_5$	6.22	0.70	4.54	256.34	242.30	224.65	81.85	79.35	77.95	149.25	132.18	122.2
T$_6$	6.16	0.71	4.59	255.35	240.89	223.09	82.35	80.65	78.35	150.74	131.92	125.85
T$_7$	6.21	0.70	4.55	254.07	243.20	228.02	82.35	80.32	78.86	151.53	134.23	126.12
T$_8$	6.15	0.71	4.57	254.45	241.20	225.43	81.32	79.35	77.42	150.12	132.83	123.36
T$_9$	6.19	0.70	4.51	256.85	243.25	232.65	84.36	81.25	78.38	150.45	137.6	129.32
T$_{10}$	6.11	0.70	4.61	256.64	243.52	231.73	83.45	80.32	78.26	149.32	134.58	126.2
T$_{11}$	6.18	0.71	4.59	255.63	244.80	233.72	84.32	81.32	79.32	152.15	140.23	130.25
T$_{12}$	6.21	0.72	4.61	256.12	244.54	230.76	83.65	80.66	78.23	151.82	136.52	127.85
T$_{13}$	6.20	0.71	4.62	256.19	245.60	237.41	85.57	82.25	80.35	152.2	142.58	132.87
CD (p=0.05)	NS	NS	NS	NS	8.2	7.9	NS	3.28	2.34	NS	9.2	10.2

See table 2 for treatment details; Package of practices: 6.5 t ha^{-1} FYM, 13:25:25 kg NPK ha^{-1} + 4 kg ZnSo$_4$

PGPR and higher electrical conductivity (0.73) in treatment receiving only package of practices.

The available nitrogen, phosphorous and potassium in the soil at 30 DAS was non-significant but this was differed significantly at 60 DAS and after harvest of crop by the foliar application of water-soluble fertilizers and PGPR (Table 4). Significantly higher available nitrogen, phosphorous and potassium (245.60, 82.25 and 142.58 kg ha^{-1}, respectively) at 60 DAS and at after harvest of the crop was in treatment receiving T$_1$+19:19:19 @ 1 per cent + mono potassium phosphate @ 1 per cent at 30 and 45 DAS + PGPR (237.41, 80.35 and 132.87 kg ha^{-1}, respectively) followed by T$_1$+19:19:19 @ 1 per cent + mono potassium phosphate @1 per cent at 30 DAS+ PGPR at 60 DAS and after harvest of the crop as compared to control. Consequently, lower available nitrogen, phosphorous and potassium were observed in the treatment receiving an only package of practices without any foliar spray. The soil fertilization, N$_2$-fixation (*Rhizobium* sp.), mineralization, nutrient solubilization process and production of organic acids due to the decomposition of organic matter by microorganisms, which cover on sesquioxide and thus reduce the phosphate fixing capacity (Rajput et al 2016). All these activities make greater availability of nutrients in soil. Lower availability of N, P and K in the soil at later stages of the crop and after harvest of crop. This might be due to the increased nutrient absorption from soil as crop growth advances. Application of liquid PGPR increases nutrient availability in the rhizosphere through fixation, mobilization and solubilization and facilitates easy for uptake.

CONCLUSION

The foliar application of water-soluble fertilizers and liquid PGPR along with the package of practice significantly influences the soil nutrient status, foliar application of 19:19:19 and MPP @1 % at 30 and 45 DAS facilitates rapid absorption and assimilation of applied nutrients, translocation results in improving the crop nutrient content and nutrient uptake of blackgram which is directly reflected on the final yield.

AUTHOR CONTRIBUTIONS

RT Chethan Babu: Conceptualization and Execution of field experiment and laboratory analysis, data analysis, writing, NS Mavarkar: Conceptualization of research work, supervision, BR Praveen: Preparation of manuscript, editing, R Dileep: Laboratory analysis, Data analysis and S Sudarshan: Editing.

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Crop Residue Recycling In Generating Nutrient Rich Organic Manures: Experiences from Rice Based Integrated Farming System

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Abstract: Two different experiments on crop residue recycling were carried out at the Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala Agricultural University from 2018 to 2020. Paddy straw, the major crop residue from rice based cropping systems was utilised as resource base for both the experiments. Different paddy straw composts generated from the first experiment through vermicomposting, co - composting and microbial composting techniques were evaluated for use as potting media component in a pot culture trial with bhindi as test crop. Composts generated in the second experiment through co composting of paddy straw with cow dung and poultry manure in the ratio 8:1:1 and with goat manure and poultry manure in the ratio 4:1:1 (both on volume basis mixing of inputs) were rich in plant nutrients. These composts when substituted for the FYM component of potting media, recorded enhancement in the uptake of major nutrients, fruit yield and quality of okra. Use of these composts as ingredient of potting media recorded higher net returns and B: C ratio as well. In the second experiment, one month old partially withered paddy straw was bio recycled through co - composting strategies using nitrogen resources cow dung, poultry manure, goat manure and glyricidia leaves or their combinations. The different composts generated were evaluated in field culture for organic nutrition of fodder maize var. *African Tall*. Co - composting of paddy straw with goat manure and poultry manure (4:1:1 ratio on volume basis) produced nutrient rich compost and on substituting this compost for chemical fertilisers on N equivalent basis, higher fodder yield, net returns and B : C ratio were recorded comparable with the integrated nutrient management package for fodder maize recommended by KAU.

Keywords: Crop residues, Integrated farming system, Paddy straw, Goat manure, Poultry manure

Crop residues are the leftover organic materials after harvesting or processing of crops and are valuable carbon inputs which could be recycled to soil to improve soil health. India generates around 500-550 million tons of crop residues annually (GOI 2016). Integrated Farming Systems (IFS) which promote sequential/multiple cropping for efficient utilisation of land resources generate substantial quantities of crop residues. Organic materials including dung and droppings are generated in IFS by dairy and poultry components. All these could be effectively utilised in generating quality organic manures within the farms (Athira et al 2021)

Rice based farming systems are characterized with the production of large quantities of crop residues mainly paddy straw. Straw though finds use as fodder for milch animals and as base material for mushroom production, largely goes as waste as a result of improper storage and drying. Mostly in double cropped conditions, at least one harvest falls during wet season which limits the chances of spreading and drying of straw resulting in mouldy growth considerably reducing the feed value of straw, which is then discarded as bio waste in fields. However in the present scenario, with the increasing trend towards organic farming, recycling of all possible organic resources assumes greater importance. However,

there are limitations in recycling paddy straw as such to soil due to bulky volume, slow degradation and short term negative effect of nitrogen immobilization (Hu et al 2016). Composting of paddy straw is an alternate option to recycle the nutrients contained in it. Based on the above, studies were conducted as two different experiments in rice based integrated farming system at the Integrated Farming System Research Station (IFSRS), Karamana, Kerala Agricultural University in recycling paddy straw for crop production. Different composting strategies were tried out in the first experiment to generate paddy straw composts which were then utilised as potting media component for container cultivation of vegetable crop okra. Co - composting of partially withered paddy straw with different organic resources were also attempted and the composts generated were used for organic nutrition of summer crop fodder maize raised in rice fallows.

MATERIAL AND METHODS

Experiment I on bio recycling of paddy straw using different technologies was carried out at IFSRS during the period from March to August, 2018. Different treatments followed for composting of paddy straw (Table 1) and the composition of paddy straw (Table 2). The statistical design

followed was completely randomised design with eight treatments and three replications. One week old straw of medium duration rice variety *Uma* was used for composting. Paddy straw sprinkled with water and stalked overnight was mixed with cow dung, poultry manure or both in different ratios

Table 1. Different treatments on paddy straw composting followed in Experiment I

Vermicomposting

T_1 - Paddy straw + cowdung (8:1) + earthworms

T_2 - Paddy straw + cowdung (6:1) + earthworms

T_3 - Paddy straw + cowdung (4:1) + earthworms

Co - composting

T_4 - Paddy straw + poultry manure (8:1)

T_5 - Paddy straw + poultry manure (6:1)

T_6 - Paddy straw + poultry manure (4:1)

T_7 - Paddy straw + cowdung + poultry manure (8:1:1)

Microbial composting

T_8 - Paddy straw + Urea + Pleurotus (For 100 kg straw, 500 g urea and 150 g Pleurotus)

Table 2. Composition of paddy straw used in Experiment I and II

Parameters	Expt. I	Expt. II
Lignin (%)	26	19
Cellulose (%)	54	30
Major nutrients (%)		
N	0.68	0.22
P	0.12	0.15
K	1.35	1.38
Micro and beneficial nutrients (mg kg^{-1})		
Fe	544.2	262.75
Cu	23.88	27.03
Mn	144.19	637.5
Zn	36.31	31.05
B	3.24	4,24
C: N ratio	60:1	39:1

on volume basis for co-composting and was filled in concrete pits of size 1 m^3. For vermicomposting treatments, earthworms (*Eudrillus euginea*) were introduced @ 1000 nos per 1 m^3 pit after 10 days of initial degradation when the heat in composting piles was reduced. Sufficient moisture levels were maintained in the composting material by periodic sprinkling of water. The materials were turned twice a week to ensure aeration and uniform decomposition. Mushroom species *Pleurotus sajor-caju* was utilised for enhancing decomposition of paddy straw in microbial composting. The nutrient content of the different composts are detailed in Table 3.

Pot culture study was conducted to evaluate the different composts with KAU hybrid okra var. *Manjima* as the test crop. These composts were used as component of potting media (Soil, rock sand, coir pith compost and paddy straw compost well mixed in the ratio 1: 0.5: 0.5: 1 on volume basis and filled @ 13 kg media per grow bag. For the control treatment, FYM was used instead of paddy straw compost in the same proportion. In treatments T_1 to T_8, the 8 different composts generated were substituted for the FYM portion of potting media. In T_9, conventional potting media i.e., soil, sand and FYM (1:1:1 on volume basis) was used. The crop was nourished as per the recommendations of KAU Package of Practices (KAU, 2016). Basal organic manure was supplied through FYM @ 130 g per plant. The basal dose of chemical fertilizers was supplied as urea, rock phosphate and muriate of potash @ 0.78, 1.26 and 0.76 g per plant, respectively. Top dressing with 0.78 g of urea per plant was done one month after planting. Data on the nutrient uptake, yield, quality and economics of okra as influenced by different potting media.

The different treatments followed in Experiment II are given in Table 6. Partially degraded, one month old straw of medium duration rice variety *Uma* was made used in the experiment II. The composition of the straw and the nutrient status of composts were estimated (Table 2, 6). The

Table 3. Nutrient content of different composts in Experiment I

Treatments	Major nutrients (%)			Micro nutrients (mg kg^{-1})				
	N	P	K	Fe	Cu	Mn	Zn	B
T_1	1.83	0.48	2.18	1189.67	28.15	158.57	174.27	12.92
T_2	1.90	0.51	2.22	1244.33	33.72	159.93	186.10	13.16
T_3	2.12	0.58	2.58	2001.33	37.80	162.03	187.77	13.50
T_4	2.06	0.63	2.70	2251.33	27.32	170.30	180.23	14.61
T_5	2.22	0.79	2.78	2998.67	32.30	184.07	191.83	16.55
T_6	2.67	0.93	3.15	3586.67	34.21	187.60	217.37	19.74
T_7	2.40	0.85	3.03	2358.67	28.45	190.57	170.90	17.90
T_8	1.57	0.27	1.71	1084.33	26.61	154.80	163.20	11.28
CD (p = 0.05)	0.317	0.129	0.591	619.975	-	-	-	2.749

composts generated were used in organic nutrition of fodder crop maize var. *African Tall* raised in summer rice fallows. The field experiment was laid out in randomised block design with eight treatments and three replications. In treatments T_1 to T_7, organic crop nutrition was followed using composts 1 to 7 respectively. T_8 followed an integrated nutrient management package as per KAU recommendation. FYM @ 10 t ha^{-1} was applied as basal organic dose uniformly for all the treatments. For treatments 1 to 7, organic crop nutrition was followed and the respective composts were applied on N equivalent basis to substitute inorganic N requirement avoiding chemical fertilizers.

RESULTS AND DISCUSSION

Experiment I

Nutrient content of composts: Treatment T_6 had the highest content of major and micronutrients followed by T_7 (Table 3). The micronutrient content of different composts were statistically similar except for Fe and B. Treatment T_6 recorded higher contents of both Fe and B. Higher N content of T_6 could be related with the higher N content of poultry manure (2.3%) used for composting, compared to cow dung (1.21%). Furthermore, the improved N content of poultry manure might have accelerated the growth of nitrifying bacteria, contributing to increased level of N in final compost. Abdelhamid *et al.* (2004) observed that as the quantity of poultry manure added to the initial material increases, total N content of paddy straw compost also increases. Poultry manure used for the experiment was rich in P (1.4 %) over cow dung (0.4 %) and hence the composts produced using poultry manure as an ingredient naturally had higher P content. Similarly, the higher K content registered in T_6 and T_7 could be due to the increased amount of K supplied by poultry manure (1.35%) compared to cow dung (0.6%).

Nutrient uptake and crop yield of okra: Nutrient uptake (Table 4) was high for T_6 and T_7 which could be attributed to the nutrient richness of these composts (Table 3) and hence more availability for uptake. Crop yields were also higher for these two treatments attributing to higher nutrient uptake which lead to improved crop nutrition.

Quality parameters of okra: Higher and comparable crude protein content were recorded by treatments T_6 and T_7 (Table 5). The crude fibre ranged from 1 to 17.90 per cent in okra fruits grown in different media. T_7 recorded lower crude fibre content. Vitamin C content ranged from 10.53 to 21.05 mg 100 g^{-1} and T_7 recorded higher content of vitamin C. The enhancement in quality parameters could be well related with better crop nourishment. Singh *et al.* (2020) reported better quality aspects in okra with an integrated nutrient supply which well nourished the crop.

Economics of cultivation: Net return was higher and comparable for treatments T_7 (Rs.7.04 bag^{-1}) and T_6 (Rs. 6.01 bag^{-1}) (Table 6). Lowest net return was for T_1 (Rs. -19.99 bag^{-1}), wherein paddy straw vermicomposted with cow dung in the ratio 8:1 (volume basis) was used as the potting media component. B: C ratio followed the same trend as net return. The treatment T_7 had the highest BCR of 1.23, comparable to T_6 (1.20). The lowest BCR of 0.51 was for T_1.

Experiment II

Nutrient content of composts: Nutrient status of different composts generated by different co-composting methods are given (Table 8). Co-composting methods using, different organic manures as nitrogen source could significantly influence the total N, P and K content of rice straw composts. Rice straw co - composted with goat manure and poultry manure in the ratio 4:1:1 on volume basis (T_6) had higher N (3.30%), P (0.98%) and K (3.22%) contents. Treatments T_4, T_5 and T_7 recorded comparable values and closely followed T_6

Table 4. Nutrient uptake and yield of bhindi as influenced by different potting media

Treatments	Nutrient uptake (kg per plant)			Fruit yield (kg per plant)	Number of fruits per plant	Average weight of fruit per plant (g)
	N	P	K			
T_1	1.17	0.14	1.61	0.345	17.33	22.93
T_2	1.56	0.28	2.13	0.482	23.00	23.78
T_3	1.74	0.31	2.36	0.508	23.67	24.21
T_4	2.11	0.32	2.45	0.515	25.67	24.71
T_5	2.52	0.33	2.50	0.534	26.00	25.21
T_6	2.73	0.42	2.96	0.590	26.67	26.26
T_7	2.92	0.48	2.88	0.619	27.67	27.05
T_8	1.24	0.15	1.91	0.382	19.00	22.59
T_9	1.28	0.23	1.81	0.361	18.33	21.07
CD (p = 0.05)	0.350	0.124	0.353	0.0390	3.734	2.272

with regard to content of major nutrients. Co-composting methods had a significant influence on the content of Fe, Cu, Mn, Zn and B micronutrients. Treatment T_6 (rice straw co-composted with goat manure and poultry manure in the ratio 4:1:1 on volume basis) recorded significantly higher contents of Fe (3201.66 mg kg^{-1}), Cu (45.58 mg kg^{-1}), Mn (1096.17 mg kg^{-1}, Zn (280.40 mg kg^{-1}) and B (19.97 mg kg^{-1}). T_8 (natural composting of rice straw) had lower content of micronutrients and was comparable to T_1 and T_2 mostly.

Nutrient uptake and crop yield: The nutrient uptake data are given in. Uptake of N was higher (179.25 kg ha^{-1}) for the INM treatment T_8 (basal FYM + soil test based application of chemical fertilizers) and was on par with T_6 (rice straw co-composted with goat manure and poultry manure in the ratio 4:1:1 as nutrient source) (Table 9). The lower N uptake was with T_1 (126.83kg ha^{-1}) comparable to T_3 and T_2. T_8 registered higher P uptake of 21.28 kg ha^{-1} which was on par with treatment T_6. Higher uptake of K (198.04 kg ha^{-1}) was for T_8 and comparable to T_6. The results suggest the comparable performance of organic nutrition using paddy straw compost

Quality parameters of test crop: Among different treatments, T_8 (KAU POP recommendation combining organic and inorganic nutrients) recorded a higher crude protein content (8.26 per cent) and was comparable to T_6 and T_4 followed by T_5 *i.e.* plants nourished under organic nutrition using rice straw composts. The treatments T_1, T_3, T_2 and T_7 recorded lower and comparable crude protein content.

Table 5. Quality parameters of bhindi fruit as influenced by different potting media

Treatments	Crude protein (%)	Crude fibre (%)	Ascorbic acid (mg 100 g^{-1})
T_1	11.55	17.90	10.53
T_2	12.72	16.70	12.28
T_3	13.65	15.23	14.04
T_4	17.62	15.47	12.28
T_5	17.97	14.93	17.54
T_6	19.25	14.37	19.30
T_7	21.12	11.10	21.05
T_8	12.25	16.7	12.28
T_9	12.37	19.3	10.53
CD (p = 0.05)	1.622	0.978	4.286

Table 6. Different treatments followed in Experiment II

Treatment	Co- composting techniques (Volume basis)
T_1	Rice straw + cow dung (4:1)
T_2	Rice straw + goat manure (4:1)
T_3	Rice straw + poultry manure (4:1)
T_4	Rice straw + cow dung + goat manure (4:1:1)
T_5	Rice straw + cow dung + poultry manure (4:1:1)
T_6	Rice straw + goat manure + poultry manure (4:1:1)
T_7	Rice straw + cow dung + glyricidia leaves (4:1:1)
T_8	Natural composting (Rice straw alone as control)

Table 7. Economics of bhindi and fodder maize as influenced by different treatments

Treatments	Net returns (Rs ha^{-1})	B : C ratio	Net returns (Rs ha^{-1})	B : C ratio
T_1	-19.99	0.51	4320	1.03
T_2	-9.10	0.76	12349	1.09
T_3	-4.72	0.87	10823	1.08
T_4	0.58	1.01	20510	1.14
T_5	2.51	1.09	21246	1.15
T_6	6.01	1.20	27661	1.20
T_7	7.04	1.23	20665	1.15
T_8	-15.92	0.59	39814	1.31
T_9	-7.32	0.75	513.43	0.02
CD (p = 0.05)	2.394	0.073	4320	1.03

Table 8. Nutrient status of composts generated from Experiment II

Treatments	Major nutrients (%)			Micro nutrients (mg kg^{-1})				
	N	P	K	Fe	Cu	Mn	Zn	B
T_1	2.59	0.55	2.39	1239.83	18.17	447.08	148.47	14.10
T_2	2.88	0.73	2.60	1299.50	19.62	645.73	161.50	16.83
T_3	2.78	0.79	2.45	1875.17	22.52	834.17	177.40	17.63
T_4	3.04	0.89	2.94	3031.83	31.90	908.75	244.85	17.93
T_5	2.99	0.93	2.86	3187.00	35.25	1053.75	244.67	18.77
T_6	3.30	0.98	3.22	3201.66	45.58	1096.17	280.40	19.97
T_7	2.93	0.82	3.00	1788.33	24.48	900.00	211.85	17.53
T_8	1.2	0.35	1.95	807.16	12.65	413.75	43.10	12.97
CD (p = 0.05)	0.230	0.090	0.160	778.873	8.452	177.160	71.190	0.904

Table 9. Nutrient uptake, yield and quality of fodder maize as influenced by different composts

Treatments	Nutrient uptake (kg per ha)			Green fodder yield (t ha^{-1})	Crude protein (%)
	N	P	K		
T$_1$	126.83	11.99	142.17	29.89	7.94
T$_2$	130.85	13.14	145.32	31.05	8.08
T$_3$	128.45	12.37	143.48	29.94	8.00
T$_4$	171.29	18.78	190.56	32.67	8.17
T$_5$	169.29	17.38	189.26	32.23	8.11
T$_6$	174.34	20.41	195.19	33.11	8.19
T$_7$	142.75	15.46	163.68	32.20	8.08
T$_8$	179.25	21.28	198.04	33.56	8.26
CD (p = 0.05)	5.160	1.153	6.346	2.030	7.94

Economics of cultivation: The net returns and B: C ratio of okra cultivation are presented in Table 6. Net return was highest for treatment T$_8$ and T$_6$ (Table 6). This could be attributed to the higher yield obtained under these treatments. The lowest net returns were in T$_1$ (Rs. 4320 ha^{-1}), where rice straw co-composted with cow dung in the ratio 4:1 was used as organic manure for fodder maize. The treatment T$_8$ registered the highest BCR of 1.31, followed by T$_6$. Lower BCR of 1.03 was in T$_1$ comparable to T$_3$.

CONCLUSION

Co - composting of paddy straw with poultry manure in the ratio 4:1 or with cow dung and poultry manure in the ratio 8:1:1 were the best methods for production of nutrient rich compost with high recovery in a short period, compared to vermicomposting and microbial composting. Substituting the above composts for FYM in potting medium could result in better growth, yield attributes, yield and net income of bhindi grown in pot culture. With respect to the quality parameters of okra, paddy straw co - composted with cow dung and poultry manure in the ratio 8:1:1(volume basis) was superior. Co - composting in the ratio 4:1:1 (volume basis) also generated composts rich in plant nutrients . When utilized for organic crop nutrition of fodder maize African Tall, these composts could result in comparable yield and economics as that obtained with the integrated nutrient management package recommended by KAU. Thus the superiority of paddy straw composts both as component of potting media and as quality organic manure were established.

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Yield and Quality of Aromatic Rice (*Oryza sativa* L.) Varieties under Nutrient Management in Organic Environment of Coastal Odisha

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Abstract: Organic aromatic rice can be raised with recommended dose of nitrogen (RDN) through farmyard manure (FYM), vermicompost (VC) and neem cake (NC). An experiment was conducted at Bhubaneswar, Odisha, India during *kharif* 2022 comprising four aromatic rice cultivars, 'Geetanjali', 'Poornabhoga', 'CR Dhan 910' and 'Nua Chinikamini' and four manuring sources, FYM (100% RDN), FYM (40% RDN)+ VC (30% RDN)+ NC (30% RDN), FYM (50% RDN)+ VC (25% RDN)+ NC (25% RDN) and FYM (60% RDN)+ VC (20% RDN)+ NC (20% RDN) in split plot design with three replications. The FYM, VC and NC had nitrogen content of 0.46, 3.0 and 4.4%, respectively. Among varieties, 'Poornabhoga' was the best for growth and yield attributes and produced grain yield of 2.95 t/ha. Among manuring sources, application of FYM (40% RDN)+ VC (30% RDN)+ NC (30% RDN) recorded the maximum growth , yield attributes and grain yield of 3.05 t/ha. Among treatment combinations, rice variety 'Poornabhoga' with application of 60kg N/ha as 24kg N/ha (FYM) + 18kg N/ha (VC)+ 18kg N/ha (NC) proved to be the best and produced the maximum yield of 3.59 t/ha. Among rice varieties, 'Geetanjali' had the maximum milling percent (71.67%), head rice recovery (63.75%), kernel length: breadth ratio (3.72), whereas 'Nua Chinikamini' had the maximum hulling % (77.50%), kernel elongation ratio (1.84) and volume expansion ratio (3.66). For higher yield and quality of aromatic rice, the rice cultivar 'Poornabhoga' should be grown with application of 24+18+18 kg N/ha as FYM+VC+NC, respectively.

Keywords: Head rice recovery, Hulling, Milling, Neem oilcake, Vermicompost

There is an upward trend in demand for quality rice worldwide due to change in eating habits of people caused by hike in per capita income and improvement of economic condition (Rashid et al 2016). Aromatic rice has good taste, eating qualities and export potential. It fetches a much higher price than ordinary brand rice (Mannan et al 2012, Roy et al 2018). Basmati type of aromatic rice includes slender and long to very long grained type, while non-basmati group mainly constitutes of small, medium and long grained types. India has a rich genetic diversity of aromatic rice (*Oryza sativa* L.) cultivars whose cultivation is restricted to localized pockets in almost all the states. These varieties have unique aroma, cooking and eating qualities (Patnaik et al 2014). Due to lack of systematic efforts for the collection, evaluation and genetic improvement, such varieties are slowly disappearing. These cultivars differ greatly in phonological behavior, growth, yield attributes, yield, and quality.

In international market, importance of organic produce is increasing day by day due to health consciousness of consumers. Organic crop cultivation involves use of natural processes or products for crop management. Nutrient need of crop can be satisfied through various sources like FYM, vermicompost (VC), oilcakes, green manure, bio fertilizer, *Jeevamrut, Beejamrut, Amrutpani* etc. Indigenous aromatic

rice responds well to organic manuring. Farmyard manure is the major source of nutrient for organic production by farmers, but other sources like vermicompost and oilcakes have additional benefits that promote crop growth and development. Vermicompost is a native organic fertilizer rich in major and micronutrients, beneficial soil microbes as nitrogen fixing bacteria and mycorrhizal fungi. Besides, it contains many enzymes (amylase, lipase, cellulase and chitinase), that helps in breaking down organic matter in the soil. Neem oilcake (NC) has inhibitory effect on nitrification and hence, minimizes the rate of nitrate leaching (Murugan and Swarnam 2013). However, vermicompost and oil cakes are costlier than FYM. So, there is a need to find out a nutrient supply system comprising diverse organic sources for fulfillment of the nutrient requirement of crop and simultaneously cost effective for the farmers. Pandey and Chitale (2015) reported positive impact of application of 100% N from organic manures (1/3rd each from cow dung manure, neem cake and composted crop residue) on growth and yield attributes of Basmati rice.

Quality parameters of aromatic rice are influenced by variety and nutrient management. Bora et al (2014) reported better grain quality parameters of aromatic rice variety 'Ketakijoha' with organic manuring. Saquib et al (2017)

reported better yield and quality parameters of scented rice with superimposition of neemcake @3t/ha, FYM @12t/ha and vermicompost @6t/ha with recommended dose of fertilizer (RDF) than RDF alone. Ruan et al (2023) reported higher head rice recovery, 2-acetyl-1-pyrroline content and flavor profiles of aromatic rice with application of vermicomost @ 3t/ha compared to inorganic fertilizers. Under such circumstances, the present experiment was designed to assess the effect of cultivars and combination of organic manure sources on phenology, growth, yield, and quality of aromatic rice.

MATERIAL AND METHODS

The field experiment was conducted at Agricultural Research Station, SOADU, Binjhagiri, Chhatbar, Khordha, Odisha during *kharif* 2022. The experimental site is located at 20^0 23' N latitude and 85^0 83' E longitude, and 20 km away from the city of Bhubaneswar with an altitude of 45 meters above mean sea level. The Research Station comes under East Coast Plains and Hills Region of India. The treatments comprising four aromatic rice varieties viz., V_1-'Geetanjali' (mutant of Basmati 370), V_2-'Poornabhoga' (mutant of Pusa Basmati 1), V_3-'CR Dhan 910' (cross of Swarna and Geetanjali) and V_4-'Nua Chinikamini' (pureline selection from landrace) and four manuring sources viz., M_1- FYM (100% recommended dose of nitrogen or RDN), M_2- FYM (40% RDN)+ VC (30% RDN)+ NC (30% RDN), M_3- FYM (50% RDN)+ VC (25% RDN)+ NC (25% RDN) and M_4- FYM (60% RDN)+ VC (20% RDN)+ NC (20% RDN) were tried in split plot design with three replications. The experimental soil was sandy loam in texture with bulk density 1.66 g/cc, acidic in reaction (pH 5.4), medium in organic carbon (0.52%), medium in available nitrogen (256.5 kg/ha), low in available phosphorus (10.5 kg/ha) and medium in available potassium (210.8 kg/ha). Recommended dose of 60 kg nitrogen/ha was applied through organic manures as per treatment specifications. The seed was sown in the raised bed nursery on 30 June. After puddling of the experimental field, layout was done on 18 June, neem oilcake was applied a week before on 19 June and FYM and vermicompost were applied on 25 June. The seedlings were transplanted in the main field on 26 July 2022 with spacing of 20 cm × 15 cm.

Days to various phenophases (50% flowering and physiological maturity) was recorded based on 10 hills/plot. The crop growth rate values were computed by using the following formula.

$$\text{Crop growth rate (CGR)} = \frac{W_2 - W_1}{t_2 - t_1} \text{ g/m}^2\text{/day}$$

Where, w_1 and w_2 were total dry weight per unit area at time t_1 and t_2 respectively.

After proper drying, plot-wise grain yields were recorded and expressed as t/ha. The length and breadth of grain and kernel were measured by using slide calipers. Quality parameters were studied as described below.

Hulling percentage: For determining hulling percentage, 100g of grain sample was weighed. The clean sample was shelled with the Satake Sheller. The samples were hulled, and weights of de-hulled grains were recorded. Hulling percentage was determined by formula (Hallick and Kelly 1959).

$$\text{Hulling percentage} = \frac{\text{Weight of brown rice (g)}}{\text{Weight of paddy (g)}} \times 100$$

Milling percentage: The hulled samples were milled, and weight of milled grains was recorded. Milling percentage was determined by

$$\text{Milling percentage} = \frac{\text{Weight of milled rice (g)}}{\text{Weight of paddy (g)}} \times 100$$

Head rice recovery percentage: After milling, the whole and broken grains were separated. The per cent of head rice or unbroken rice grain were determined based on the initial weight of the rough rice per cent of total rice or sum total of head rice and all classes of broken rice.

$$\text{Head rice recovery percentage} = \frac{\text{Weight of head polished rice (g)}}{\text{Weight of milled rice (g)}} \times 100$$

Elongation ratio: Elongation ratio of cooked kernels was determined by dividing the length of cooked kernel to length of uncooked kernel (Juliano and Betchel 1985).

$$\text{Elongation ratio} = \frac{\text{Length of cooked kernel (mm)}}{\text{Length of raw kernel (mm)}}$$

Volume expansion ratio: Volume expansion ratio was determined from the ratio of cooked volume rice to that of the uncooked rice (Sidhu et al 1975). Rice kernel of 5g weight was added to 15ml of water in a test tube and rise in volume (x ml) was noted. Rice grain sample was cooked for 20 mins in a thermostatically controlled heating mantle at 90 $^\circ$C and 15ml of water was added to the cooked rice. Then rise in volume (y ml) was noted and volume expansion ratio was found out by the following formula.

Volume Expansion Ratio = y/x

RESULTS AND DISCUSSION

Crop phenology: Among the varieties, 'Geetanjali' attained the 50% flowering stage at 99 days after sowing, whereas 'Nua Chinikamini' came to 50% flowering stage at 112 days

after sowing (Fig. 1). The variety 'Geetanjali' was the earliest to attain physiological maturity in 129 days, whereas 'Nua Chinikamini' took the longest time to attain physiological maturity stage. The varieties 'Poornabhoga' and 'CR Dhan 910' were similar for seed to seed duration and came to physiological maturity in 138-139 days. Various manuring sources failed to exert significant influence on days to 50% flowering and physiological maturity. Onset of developmental stages depends on genetical characters and climatic factors, mostly temperature. Patel et al (2014) reported variation (92-121 DAT) among aromatic rice varieties for days to attainment of 50% flowering.

Growth attributes: The aromatic rice varieties exerted significant influence on plant height and tillers/hill (Table 1). Plant height increased progressively from 30 days after transplanting (DAT) till harvest. At 30 DAT, 'Nua Chinikamini' had the minimum vertical growth and other three varieties
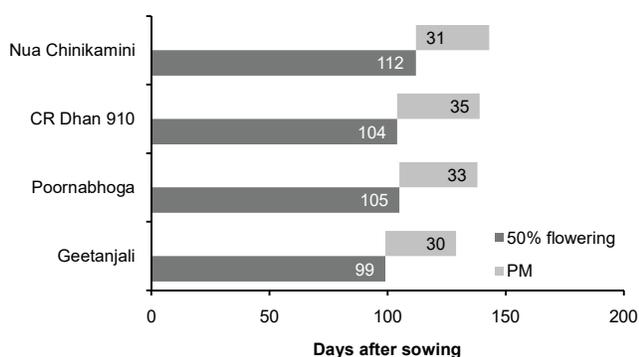
PM- Physiological maturity

Fig. 1. Effect of variety on days to attainment of phenophases

recorded significantly higher plant height. At 60 DAT, 'Gitanjali' had the maximum vertical growth, placing 'Poornabhoga' at par. The varieties 'CR Dhan 910' and 'Nua Chinikamini' recorded significantly less plant height. A differential trend was noted at physiological maturity. At physiological maturity 'Nua Chinikamini' had the tallest, whereas 'CR Dhan 910' had the shortest plant. The longest duration variety 'Nua Chinikamini' had the maximum rate of vertical growth during 60 DAT to physiological maturity. The plant height of these non-basmati aromatic rice varieties was predominantly a genetical feature. 'Nua Chinikamini' is a tall variety, whereas 'CR Dhan 910' is a semi-dwarf variety. Patnaik et al (2014) reported plant height of 'Nua Chinikamini' as 140 cm. In general, the lower plant height of the variety in the present study was due to delayed sowing, photosensitivity (short day) nature and organic mode of cultivation. Sources of manuring failed to influence plant height of aromatic rice varieties significantly at 30 and 60 DAT. At physiological maturity, the three combinations of manuring sources i.e. M_2, M_3 and M_4 recorded significantly higher plant height than M_1. Pandey and Chitale (2015) reported positive impact of manuring combinations on growth and yield attributes of basmati rice.

The varieties of rice influenced tillers/hill both at 30 and 60 days after transplanting. At 30 DAT the variety 'Poornabhoga' was the most profuse tillering with 5.6 tillers/hill, placing 'Nua Chinikamini, and 'Geetanjali' at par. The variety 'CR Dhan 910' had the minimum tillers/hill and proved significantly inferior to other cultivars. At 60 DAT, 'Nua Chinikamini' recorded the maximum tillers/hill (9.3), being at par with 'Poornabhoga' and both proved significantly superior to

Table 1. Effect of variety and manuring sources on plant height and tillers/hill of organic aromatic rice

Treatment	Plant height (cm)			Tillers/hill	
	30 DAT	60 DAT	PM	30 DAT	60 DAT
Variety					
V_1- Geetanjali	61.9	85.8	88.5	5.4	6.6
V_2- Poornabhoga	62.5	83.7	92.1	5.6	8.8
V_3- CR Dhan 910	63.4	72.4	74.9	4.8	6.3
V_4- Nua Chinikamini	52.8	70.0	104.0	5.4	9.3
CD (p=0.05)	5.0	10.6	4.2	0.5	0.9
Sources of manuring (% of RDN)					
M_1-FYM (100%)	58.5	76.7	84.8	5.1	7.4
M_2-FYM (40%)+ VC (30%)+ NC (30%)	61.0	78.8	94.2	5.6	8.1
M_3-FYM (50%)+ VC (25%)+ NC (25%)	60.9	77.5	90.3	5.3	7.7
M_4-FYM (60%)+ VC (20%)+ NC (20%)	60.3	78.9	90.1	5.2	7.7
CD (p=0.05)	NS	NS	5.8	0.3	0.5

RDN- Recommended dose of nitrogen (60kg/ha), FYM- Farm yard manure, VC- Vermicompost, NC- Neem oilcake, DAT- days after transplanting, PM-Physiological maturity, CD- Critical difference

'Geetanjali' and 'CR Dhan 910'. Mia and Shamsuddin (2011) reported higher tillers/hill with aromatic rice varieties compared to modern rice varieties. Among manuring sources, M_2 recorded the maximum tillers/hill at both 30 and 60 DAT, being at par with M_3 and M_4 at 60 DAT and M_3 at 30 DAT. This reflects superiority of combination of manuring sources compared to 100% recommended dose of nitrogen as FYM.

Both varieties and sources of manuring influenced dry matter accumulation and leaf area index significantly (Table 2). Dry matter accumulation increased progressively from 30 DAT till physiological maturity (PM). Among varieties, 'Poornabhoga' accumulated the maximum dry matter at all the three stages. The variety 'Geetanjali' ranked the second with respect to dry matter accumulation. The higher dry matter accumulation by 'Poornabhoga' was due to higher LAI and profuse tillering. At physiological maturity, 'Poornabhoga' recorded dry matter accumulation of 880 g/m^2, reflecting 22, 27 and 28% increase over 'Geetanjali', 'Nua Chinikamini' and 'CR Dhan 910', respectively. Similar dry matter accumulation by aromatic rice was reported by Yadav and Meena (2014) and Rathiya et al (2017). Among organic nutrient management practices, the manuring combinations viz. M_4 and M_2 at 30 DAT, M_3 and M_2 at 60 DAT and M_2 at 90 DAT recorded higher dry matter accumulation than M_1. Pandey and Chitale (2015) reported better efficacy of combined application of manuring sources (FYM, VC and NC) on dry matter accumulation in rice.

Among varieties, 'Poornabhoga' recorded the maximum LAI of 1.37 and 4.13 at 30 and 60 DAT, respectively. The variety 'Geetanjali' at 30 DAT and 'Geetanjali' and 'Nua chinikamini' at 60 DAT recorded statistically similar LAI.

Higher LAI up to the optimum leads to higher photosynthesis and dry matter accumulation. The higher dry matter production in case of 'Poornabhoga' and 'Geetanjali' was due to higher LAI that increased photosynthesis. Among combination of manuring sources, M_2 recorded the maximum LAI at 30 and 60 DAT. Manuring combinations with higher proportion of vermicompost and neem cake could ensure sustained supply of nitrogen to the crop. Inhibitory effect of neem cake on nitrogen facilitated slow release of N and minimization of nitrate leaching. Sustained N availability promoted leaf expansion leading to higher LAI.

Crop growth rate: Crop growth rate values during 30-60 DAT intervals were higher than that during 60 DAT-physiological maturity (Table 3). Among varieties, 'Poornabhoga' had the maximum crop growth rates of 11.1 $g/m^2/day$ and 8.3 $g/m^2/day$ during 30-60 DAT and 60 DAT-physiological maturity, respectively, keeping 'Geetanjali' at par. Higher growth rate in these two varieties is reflection of genetical features of the varieties. Among combination of manuring sources, M_2 recorded the minimum CGR of 10.1 and 8.1 $g/m^2/day$ during 30-60 DAT and 60 DAT-physiological maturity, respectively, and M_3 recorded statistically similar CGR values. Application of higher proportion of N through vermicompost and neem oil cake recorded higher CGR. Sustained supply of N matching to the crop growth under these two combinations led to higher crop growth rates.

Yield attributes: Both varieties and manuring sources influenced yield attributes of aromatic rice significantly (Table 3). Among varieties, 'Poornabhoga' recorded the maximum of 221 panicles/m^2 and 'Nua Chinikamini' with 210 panicles/m^2 remained at par. Both these varieties recorded significantly higher tillers/hill than other varieties. Among

Table 2. Effect of variety and manuring sources on dry matter accumulation and LAI of organic aromatic rice

Treatment	Dry matter accumulation (g/m²)			Leaf area index	
	30 DAT	60 DAT	PM	30 DAT	60 DAT
Variety					
V_1	123	432	722	1.31	3.96
V_2	146	478	880	1.37	4.13
V_3	94	379	688	1.17	2.72
V_4	87	339	692	1.22	3.75
CD (p=0.05)	11	25	57	0.06	0.40
Sources of manuring (% of RDN)					
M_1	102	385	694	1.13	3.45
M_2	119	422	797	1.39	3.91
M_3	108	425	764	1.29	3.55
M_4	122	395	727	1.25	3.65
CD (p=0.05)	10	24	27	0.08	0.26

varieties, 'Nua Chinikamini' recorded the maximum of 133 filled grains/panicle and proved superior to all other varieties. Among varieties, 'Geetanjali' had the heaviest grain and 'Nua Chinikamini' had the lightest grain with test weight of 13.37g/1000 grains. The 1000 grain weight is predominantly decided by the genetic make-up of the varieties and to some extent by climatic, edaphic and management factors. Rashid et al (2017) reported similar variable trend of aromatic rice varieties for yield attributes. They reported 255.6 filled grain/panicle in 'Kataribhoga' as against the minimum values of 130.7/panicles in 'Badshabhoga'. The variety 'Badshabhoga' had the heaviest grain with 1000 grain weight of 18.3g and the variety 'Kataribhoga' had the minimum 1000-grain weight of 11.4g.

Among manuring sources, application of M_2 recorded the maximum values of panicles/m^2 and filled grains/panicle, being at par with M_3. Application of 100% N as FYM recorded the minimum values of panicles/m^2 and filled grains/ panicle. The trend of manuring sources for yield attributes established the superiority of combination of manuring sources over application of recommended N from single organic source.

Grain yield: Among varieties, 'Poornabhoga' recorded the maximum grain yield of 2.95 t/ha, being at par with 'Geetanjali' with grain yield of 2.83 t/ha (Table 4). The variety 'Poornabhoga' produced 16 and 32% higher grain yield over 'CR Dhan 910' and 'Nua Chinikamini', whereas 'Geetanjali' produced 11 and 27% higher grain yield over 'CR Dhan 910' and 'Nua Chinikamini', respectively. The superiority of 'Poornabhoga' for grain yield was due to higher values of panicles/m^2, LAI, dry matter accumulation and tillers/hill, whereas the superiority of 'Geetanjali' for yield over two other varieties was due to higher tillers/hill, LAI and 1000-grain weight. The variety 'Nua Chinikamini' had the maximum plant height at physiological maturity, tillers/hill and panicle/m^2, but it exhibited the minimum grain yield due to the minimum test weight of grains. Grain yield can be expressed as a function of panicles/m^2, filled grains/panicle and test weight of 1000 grains. The yield levels are similar to those reported by

Table 3. Effect of variety and manuring sources on crop growth rate and yield attributes of organic aromatic rice

Treatment	Crop growth rate (g/m²/day)		Panicles/m²	Filled grains/ panicle	1000- grain weight (g)
	30-60 DAT	60 DAT-PM			
Variety					
V_1	10.3	7.6	204	72	23.85
V_2	11.1	8.3	221	94	20.51
V_3	9.5	6.3	199	91	22.07
V_4	8.4	6.7	210	133	13.37
CD (p=0.05)	0.8	1.0	13.6	9	0.75
Sources of manuring (% of RDN)					
M_1	9.4	6.5	189	88	19.98
M_2	10.1	8.1	231	104	20.13
M_3	10.6	7.3	218	101	19.88
M_4	9.1	6.9	196	97	19.80
CD (p=0.05)	0.9	0.9	13.4	6	NS

Table 4. Effect of variety and manuring sources on grain yield of organic aromatic rice

Treatment	M_1	M_2	M_3	M_4	Mean
Variety					
V_1	2.19	3.28	3.20	2.66	2.83
V_2	2.89	3.59	3.13	2.19	2.95
V_3	2.19	3.13	2.73	2.11	2.54
V_4	2.19	2.19	1.96	2.58	2.23
Mean	2.36	3.05	2.76	2.38	2.64
CD (p=0.05)	Variety (V)	Manuring (M)	V x M	M x V	
	0.22	0.15	0.34	0.29	

V x M- Variety in same or different levels of M, M x V- Manuring sources in same level of variety

Chowdhury et al (2016) for aromatic rice. They achieved grain yield of 2.11 t/ha with 'Kalazira' to the maximum of 3.33 t/ha with variety 'Binadhan-13' in Bangladesh condition. Rathiya et al (2017) reported the maximum tillers/m^2 and 1000-grain weight in variety 'Pusa Basmati-1', but the variety 'Jeerafool' recorded the maximum grain and straw yield due to higher plant height, panicle length and grains/panicle. Among nutrient management, the manure combination with higher proportion of vermicompost and neem oil cake i.e. FYM (40% RDN)+ VC (30% RDN)+ NC (30% RDN) recorded the maximum grain yield of 3.05 t/ha and proved superior to all other combination of organic manuring sources. This was due to higher values of growth and yield attributes. Increase in grain yield of rice with combination of manuring sources over single source has been earlier reported by Davari and Sharma (2010), Singh et al (2011) and Pandey and Chitale (2015). Interaction effect of variety and manuring sources were found significant for grain yield. The variety 'Poornabhoga' with application of FYM (40% RDN)+ VC (30% RDN)+ NC (30% RDN) gave the maximum grain yield of 3.59 t/ha and proved better than other combinations.

Grain quality: The aromatic rice varieties differed widely for grain quality (Table 5). The variety 'Geetanjali' had the longest grain with grain length of 10.89 mm, whereas 'Nua Chinikamini' had the shortest grain with grain length of 4.95 mm. The variety 'Geetanjali' (2.43 mm) had the maximum grain length, while 'Poornabhoga' (2.07 mm) and 'CR Dhan 910' (2.05 mm) had the minimum grain breadth. Among varieties, 'Poornabhoga' had the maximum grain length: breadth ratio, while 'Nua Chinikamini' had the minimum grain L/ B ratio. The variety 'Nua Chinikamini' had the maximum hulling % and the variety 'CR Dhan 910' had the minimum hulling %. The variety 'Geetanjali' (71.67%) had the maximum milling %, while 'Poornabhoga' had the minimum milling %. The variety 'Geetanjali' had the maximum head rice recovery percentage, whereas the variety 'Poornabhoga' had the minimum HRR percentage. Manuring sources could not cause much variation in grain quality.

Kernel quality: Among varieties, rice variety 'Geetanjali' (8.59 mm) had the maximum kernel length, while 'Nua Chinikamini' (3.32 mm) had the minimum kernel length (Table 6). 'Geetanjali' (2.31 mm) had the maximum kernel

Table 5. Effect of variety and manuring sources on grain quality parameters of organic aromatic rice

Treatment	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio	Hulling (%)	Milling (%)	HRR (%)
Variety						
V_1	10.89	2.43	4.48	76.33	71.67	63.75
V_2	9.65	2.07	4.66	72.50	56.50	35.50
V_3	8.60	2.05	4.21	70.32	64.76	56.76
V_4	4.95	2.24	2.21	77.50	70.40	51.50
Sources of manuring (% of RDN)						
M_1	8.52	2.23	3.82	74.16	65.83	51.88
M_2	8.66	2.21	3.94	74.26	65.58	52.13
M_3	8.47	2.17	3.93	74.09	65.96	51.63
M_4	8.43	2.19	3.86	74.14	65.96	51.88

Table 6. Effect of variety and manuring sources on kernel quality parameters of organic aromatic rice

Treatment	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio	Elongation ratio	VER
Variety					
V_1	8.59	2.31	3.72	1.22	3.57
V_2	5.79	1.66	3.50	1.61	3.64
V_3	5.85	1.90	3.07	1.42	3.32
V_4	3.32	2.02	1.65	1.84	3.66
Sources of manuring (% of RDN)					
M_1	5.90	2.00	2.94	1.55	3.55
M_2	6.00	1.98	3.03	1.53	3.54
M_3	5.84	1.94	3.02	1.52	3.54
M_4	5.81	1.96	2.96	1.50	3.56

VER- Volume Expansion Ratio

breadth and 'Poornabhoga' (1.66 mm) had the minimum breadth. The kernel L/B ratio value was the maximum for 'Geetanjali' (3.72) and the minimum for 'Nua chinikamini' (1.65). Lakra (2012) reported L/B ratio on Badshabhoga (3.3), Pusa Basmati (4.0), Safri (3.5), Chandrabasini (3.5) and Rajeshwari (2.7) belonging to group traditional aromatic-non basmati type, improved aromatic varieties, traditional non-aromatic basmati type, improved non-aromatic non-basmati type and improved non-aromatic, respectively. Elongation ratio refers to ratio of length of cooked kernel (mm) to length of raw kernel (mm). The elongation ratio was the maximum for 'Nua Chinikamini' (1.84) and the minimum for 'Geetanjali' (1.22). Volume expansion ratio (VER) is the ratio of cooked rice volume to raw rice volume. Among varieties, 'Nua Chinikamini' (3.66) had the maximum volume expansion ratio closely followed by 'Poornabhoga' (3.64). The maximum yielding variety 'Poornabhoga' had the kernel length: breadth ratio of 3.50 (next to Geetanjali) and the volume expansion ratio of 3.64 (next to Nua Chinikamini). The manuring sources did not differ much in volume expansion ratio.

CONCLUSIONS

The experiment comprising four varieties and four manure sources was conducted to find out the best treatment combination for better yield and quality of aromatic rice under organic environment of Coastal Odisha. It is concluded that variety 'Poornabhoga' with 60 kg nitrogen/ha through farmyard manure, vermicompost and neem cake contributing 40, 30 and 30%, respectively, excelled other combinations. Organic rice farmers should combine these three manures instead of using farmyard manure alone to fulfil the nitrogen demand of the crop and achieve desired yield and quality.

AUTHORS CONTRIBUTION

Stuti DB, SSM, BB and GS conceptualized and designed the experiment. SSM, GS, JJ and KSG conducted the field experiment and laboratory analysis work and collected data. SSM, RKS, SM, Stuti DB, Swosti DB and MP analysed the data, prepared the figures and wrote the original manuscript. BB revised the manuscript.

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Standardization of Land Preparation Method to Exhaust Tuber Reserve and Regeneration of Purple Nut Sedge (*Cyperus rotundus* L.)

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Abstract: The unmanageable proliferation of purple nutsedge (*Cyperus rotundus* L.), coupled with the persistent nature of its tubers hinders effective control through cultural and mechanical methods. Experiment was conducted during the *kharif* and summer season at College of Agriculture, Vellayani to assess the effectiveness of land preparation methods to exhaust the tuber reserve and extent of regeneration of the weed. The treatments included stale seedbed (SSB) preparation followed by chemical and mechanical methods. SSB with halosulfuron methyl (HSM) 67.5 g ha^{-1} applied at 3-4 leaf stage of the weed resulted in a higher percentage reduction in population (66.10 and 60.80%), shoot dry weight (89.66 and 81.29%), tuber dry weight (75.18 and 69.76%) during summer and *kharif*, respectively. It was comparable with glyphosate 1.5 kg ha^{-1}. During both seasons, higher weed control efficiency, lower regeneration count, and tuber viability were noted with SSB + HSM at 67.5 g ha^{-1} which was on par with SSB + glyphosate 1.5 kg ha^{-1} making it a promising alternative for depleting nutsedge tuber reserves in sandy loam with lower regeneration, especially in light of the restricted use of glyphosate.

Keywords: Halosulfuron methyl, Nutsedge tuber dry weight, Regeneration count, Stale seedbed, Tuber viability, Weed control efficiency

Purple nutsedge (*Cyperus rotundus* L.), native of India, is a persistent agricultural weed that troubles over 90 tropical and subtropical countries, infesting 52 crop varieties and causing significant yield losses in different crops such as cotton (70-85%), soybean (23-89%), direct seeded rice (42-50%), sugarcane (20-30%) and maize (10-30%), if they are not managed timely (Peerzada 2017). Its rapid propagation, with a single tuber generating 1900 plants and 8900 tubers within 31.6 square meters in a year, leads to cultivation abandonment, particularly in uplands. Thus, it was considered as one of the most troublesome invasive weeds (Chaudhary et al 2022). The resilience of the weed under various stresses is due to its vigorous subterranean tuber network, where each tuber produces multiple active buds, resulting in persistent growth along with its allelopathic effect (Webster et al 2008; Ameena et al 2015). Controlling it through cultural or mechanical means proves challenging due to the tuber viability and their ability to sprout repeatedly (Nelson and Renner 2002; Ameena et al 2014). Even herbicides have not proven entirely successful in curbing its growth due to poor translocation and the dormant nature of tuber, necessitating the use of effective chemicals like glyphosate and 2,4-D. Consequently, the use of suitable herbicides has become imperative in the battle against this persistent weed.

Glyphosate, alone or combined with 2,4-D, has shown promise in controlling purple nutsedge growth since it translocated rapidly to the tubers (Das and Yaduraju 2002,

Ameena and George 2004). However, the restricted use of these herbicides in many regions requires evaluating new and effective molecules. Chlorimuron-ethyl (CUE) and halosulfuron methyl (HSM) have displayed efficacy in reducing *Cyperus rotundus* populations and tuber viability, making them potential alternatives for control (Kaur et al 2009, Webster and Grey 2014). Reduced tuber viability (20-23.3%) and regeneration (6-8 sprouts per m^2) were documented when employing a stale seedbed along with pre-plant application, followed by directed post-emergence glyphosate application (Ameena et al 2006). However, the efficacy of the molecule in containing tuber regeneration and viability need to be checked under field condition. In this backdrop, an experiment was conducted to standardize the land preparation methods using different herbicides to exhaust tuber reserve and regeneration of purple nut sedge.

MATERIAL AND METHODS

The experiment was conducted during the summer and *kharif* season of 2022 at College of Agriculture, Vellayani in two different locations having severe nutsedge infestation with a density of more than 10 plants per sq. m. The experiment was laid out in randomized complete block design with eight treatments replicated thrice (Table 1). The stale seedbed plots were prepared by digging the field to a depth of 15 cm to break and expose the tuber chains of the weed followed by irrigation to facilitate the germination of dormant tubers. Later, the sprouted plants were sprayed with

herbicides as per treatments at one week after SSB with weed at its 3-4 leaf stage. The initial (one week after SSB) and final (six weeks after spraying) count, shoot and tuber dry weight (g/m^2) of *Cyperus rotundus* were taken using a 25 cm x 25 cm quadrant and their respective percentage reductions were worked out. Weed control efficiency (WCE) was worked out by taking the difference in weed dry weight of weedy check and corresponding treatment plot and divided by weed dry weight in weedy check plot (Mani et al 1973). Ten tubers from each treatment were collected at 6 weeks after spraying (WASP) and sown in different containers having sand to observe the tuber viability. Number of tubers sprouted were recorded after 2 weeks and tuber viability was worked out and expressed as percentage. The area of 15cm x 15cm was marked in each plot just before imposing herbicide applications. The number of nutsedge sprouts regenerated were counted at 2, 4 and 6 WASP.

RESULTS AND DISCUSSION

Influence of Land Preparation Methods on *Cyperus rotundus* L

Population: The different land preparation methods exerted significant variation in the population of nutsedge (Table 1). The initial population of *Cyperus rotundus* L. sprouted after SSB ranged between 83.11 to 135.56 per m^2 during summer, while it was between 60.44 to 78.67 per m^2 during *kharif*. Among all the treatments, SSB with glyphosate application (T$_6$) recorded lower final *Cyperus rotundus* L. population during both seasons (25.78 and 17.77 per m^2, respectively). Further, SSB with HSM at 75 g ha^{-1} (T$_3$) and at 67.5 g ha^{-1} (T$_2$) were comparable with T$_6$. The percentage reduction in *C.*

rotundus L. population was higher in T$_6$ and was on par with T$_3$ and T$_2$ in summer and *kharif*, respectively. The plots where the stimulation alone was given by way of seedbeds (T$_8$) there was a 14.74 and 38.18% increase in purple nutsedge population during both summer and *kharif*, respectively. Stale seedbed preparation had promoted the germination of dormant tubers and subsequent application of glyphosate or HSM at 3-4 leaf stage of weed had effectively controlled nutsedge population. The highest percentage reduction of nutsedge population with glyphosate in SSB was earlier reported by Ameena et al (2006). The effectiveness of SSB in combination with HSM, in managing *C. rotundus* similar to glyphosate, is supported by the findings of Manisankar et al (2022).

Shoot dry weight: The land preparation methods caused significant variation in nutsedge shoot dry weight (Table 2). The initial shoot dry weight of *C. rotundus* L. ranged from 38.85 to 129.79 g/m^2 during summer and 43.01 to 52.84 g/m^2 during *kharif*. The final shoot dry weight of *C. rotundus* L. was recorded lower in SSB with glyphosate at 1.5 kg ha^{-1} (T$_6$) (5.73 and 3.99 g/m^2) during both summer and *kharif,* respectively at 6 WASP which was comparable with SSB + HSM at 75 g ha^{-1} (T$_3$) and at 67.5 g ha^{-1} (T$_2$). On the whole, T$_6$, T$_3$ and T$_2$ recorded significantly higher percentage reduction in shoot dry weight of *C. rotundus* L. during summer as well as *kharif*. The dry weight of shoots showed an increase of 18.16% in the *kharif* season, compared to a modest increase of 2.57% during the summer, specifically when sole SSB practices were employed. This might be ample rainfall in *kharif* has allowed the weed to efficiently utilize moisture attributed to its C$_4$ pathway resulting in superior growth (Mandal et al 2022).

Table 1. Effect of different land preparation methods on population of purple nutsedge (*Cyperus rotundus* L.) per 1.0 m^2

Treatments		Summer, 2022			Kharif, 2022			Pooled data (6 WASP)
		Initial population	Final population	Percent reduction in population	Initial population	Final population	Percent reduction in population	
T$_1$	SSB with HSM at 60g ha^{-1} at 3-4 leaf stage of weed	130.67^a	58.67^b	54.60^{bc}	61.78	30.22^d	50.56^{bc}	6.29^{bcd}
T$_2$	SSB with HSM at 67.5g ha^{-1} at 3-4 leaf stage of weed	99.11^b	33.33^{cd}	66.10^{ab}	60.44	23.56^{de}	60.80^{ab}	4.24^{cd}
T$_3$	SSB with HSM at 75g ha^{-1} at 3-4 leaf stage of weed	98.67^b	32.00^d	67.97^{ab}	74.22	22.67^{de}	69.48^a	4.07^d
T$_4$	SSB with CUE at 9g ha^{-1} at 3-4 leaf stage of weed	88.00^{bc}	62.22^b	29.16^d	70.22	54.22^b	22.38^e	8.98^{bc}
T$_5$	SSB with CUE at 12g ha^{-1} at 3-4 leaf stage of weed	83.11^c	48.89^{bc}	41.34^{cd}	69.33	40.00^c	40.83^{cd}	6.78^{bcd}
T$_6$	SSB with glyphosate at 1.5 kg ha^{-1}	92.00^{bc}	25.78^d	71.47^a	66.67	17.77^e	72.97^a	3.23^d
T$_7$	SSB with mechanical destruction	135.56^a	61.78^b	52.95^{bc}	78.67	56.44^b	28.25^{de}	9.18^b
T$_8$	SSB alone	99.56^b	114.22^a	-15.87^e	73.33	101.33^a	-39.45^f	16.66^a

Note: (SSB- Stale Seedbed); (WASP-Weeks after spraying)
Figures with same letter in column do not differ significantly (CD p=0.05)

Further, the effect of HSM on nutsedge shoot dry weight was similar to glyphosate under SSB due to its rapid absorption by the foliage, facilitating its translocation throughout the entire plant causing substantial decrease in plant biomass. Maurya et al (2021) also reported that the application of HSM at 67.5, 75.0, and 150.0 g ha^{-1} resulted in significantly lower weed dry biomass for *C. rotundus*, ranging from 0.45-0.49 g m^{-2}.

Tuber dry weight: The nutsedge tuber dry weight varied significantly with respect to the land preparation methods tested (Table 2). The initial tuber dry weight of *C. rotundus* L. ranged from 157.52 to 252.96 g/m^2 during summer to 53.15 to 61.64 g/m^2 during *kharif*. However, final *C. rotundus* L. tuber dry weight was recorded lower in SSB with glyphosate at 1.5 kg ha^{-1} (T$_6$) and SSB with HSM at 75 g ha^{-1} (T$_3$) at 6 WASP (46.64 and 47.49 g/m^2, respectively) which was on par with SSB with HSM at 67.5 g ha^{-1} (T$_2$) in summer. In *kharif*, T$_6$ recorded lower final *C. rotundus* L. tuber dry weight (11.04 g/m^2) which was on par with T$_3$ and T$_2$. In general, T$_2$, T$_3$ and T$_6$ recorded significantly higher percentage reduction in tuber dry weight (75.18, 74.99 and 73.90%, respectively) followed by T$_5$ in summer. However, during *kharif*, T$_6$ and T$_3$ recorded significantly higher percentage reduction in tuber dry weight (80.78 and 76.05%, respectively) and were on par with T$_2$. An elevated tuber dry weight, with an increase of 18.97% was noticed in the summer compared to 13.04% during the *kharif* season in SSB alone control plots. The SSB treatments using HSM at 67.5 and 75 g ha^{-1} have significantly decreased tuber dry weight, showing comparable effectiveness to glyphosate. This could be achieved due to effective herbicidal translocation to tubers thereby killing the underground propagules. Webster et al (2008) observed reduced total tuber biomass with halosulfuron similar to glyphosate in purple nutsedge.

Weed control efficiency and tuber viability of *C. rotundus*: The weed control efficiency (WCE) as influenced by land preparation methods showed significant variation (Figure 1 and 2) during both summer and rainy season. Significantly higher WCE was recorded by SSB with glyphosate at 1.5 kg ha^{-1} (T$_6$), SSB with HSM at 75 g ha^{-1} (T$_3$) and SSB with HSM at 67.5 g ha^{-1} (T$_2$) in summer and *kharif* respectively. Ghosh et al (2017) observed post-emergence application of HSM 75% WG as exceptional with WCE of 86.6 to 90% at 45 days after application. Similarly, Maurya et al (2021) reported that the application of halosulfuron at rates of 67.5, 75.0, and 150.0 g ha^{-1} resulted in higher weed control efficiency.

Tuber viability was significantly affected by different land preparation methods. In both seasons, SSB with glyphosate at 1.5 kg ha^{-1} (T$_6$) and SSB with HSM at 75 g ha^{-1} (T$_3$) recorded significantly lower tuber viability (13.33 and 26.67%) and (6.67 and 13.33%), respectively. They were on par with SSB with HSM at 67.5 g ha^{-1} (T$_2$). The treatment T$_2$ recorded about 66.67 and 80 percent reduction in tuber viability over plots where SSB alone was employed (T$_8$) respectively in both seasons. This implied that the herbicidal effect might have made the tubers incapable of growth after new shoots had emerged. Giraldeli et al (2020) also found that halosulfuron, applied @ 105 g ha^{-1}, significantly decreased the number of viable tubers by 62% (4-5 leaves), 54% (5-7 leaves) and 46% (7-8 leaves) at 90 days after application.

Regeneration count of *Cyperus rotundus* L.: No signs of regeneration were observed at 2 weeks after spraying, but the reappearance of purple nutsedge became apparent at 4 and 6 weeks after herbicide application. The lower regeneration count per 0.15 sq. m was recorded in SSB with

Table 2. Effect of different land preparation methods on shoot and tuber dry weight (g/m^2) of purple nutsedge (*Cyperus rotundus* L.)

Treatments	Shoot dry weight							Tuber dry weight						
	Summer, 2022			*Kharif*, 2022			Pooled data (6 WASP)	Summer, 2022			*Kharif*, 2022			Pooled data (6 WASP)
	Initial	Final	% reduction	Initial	Final	% reduction		Initial	Final	% reduction	Initial	Final	% reduction	
T$_1$	100.13^b	22.80^b	77.52^a	43.65	19.51^d	54.80^b	5.28^{bc}	234.93^{ab}	80.32^b	65.48^{ab}	53.15	22.93^c	56.35^b	4.28^{bc}
T$_2$	75.87^{bcd}	7.13^d	89.66^a	43.01	7.93^e	81.29^a	1.88^{cd}	195.56^{bc}	49.01^{cd}	75.18^a	49.92	15.00^{cd}	69.76^{ab}	2.70^c
T$_3$	70.07^{cd}	6.23^d	90.67^a	48.27	6.81^e	85.53^a	1.63^{cd}	188.11^{bc}	47.49^d	74.99^a	57.40	13.75^{cd}	76.05^a	2.55^c
T$_4$	54.56^{de}	30.37^b	41.86^c	49.45	29.76^{bc}	40.45^{bc}	7.52^b	176.60^c	78.29^{bc}	55.20^b	59.39	43.52^b	26.66^c	6.00^b
T$_5$	38.85^e	15.00^c	61.07^b	46.05	22.63^{cd}	48.38^{bc}	4.70^{bcd}	157.52^c	67.57^{bcd}	57.44^b	53.75	35.42$_b$	32.44^c	4.99^{bc}
T$_6$	61.64^{cde}	5.73^d	90.81^a	48.27	3.99$_e$	91.62^a	1.22^d	180.60^c	46.64^d	73.90^a	56.88	11.04^d	80.78^a	2.29^c
T$_7$	129.79^a	26.64^b	79.10^a	46.99	35.07^b	25.39^c	7.71^b	252.96^a	88.45^b	64.24^{ab}	55.65	39.85^b	28.19^c	5.97^b
T$_8$	82.45^{bc}	84.57^a	-4.26^d	52.84	62.43^a	-23.13^c	18.38^a	201.12^{bc}	239.29^a	-20.05^c	61.64	69.70^a	-15.32^d	12.86^a

WASP- Weeks after spraying. See Table 1 for treatment details
Figures with same letter in column do not differ significantly (CD-p 0.05)

glyphosate at 1.5 kg ha^{-1} (T$_6$), SSB with HSM at 75 g ha^{-1} (T$_3$) and SSB with HSM at 67.5 g ha^{-1} (T$_2$) at 4 and 6 WASP in summer (Fig. 1). However, in *kharif*, T$_6$ lower regeneration count (1.00) and was on par with T$_3$ at 4 WASP. In the same season, T$_6$, T$_3$ and T$_2$ recorded lower regeneration count at 6 WASP (Fig. 2). In the control plot there was a rise in the regeneration of purple nutsedge, amounting to 7.14% during the summer and 12.14% during the *kharif* season. Ameena et al (2013) demonstrated the highest percentages of regrowth

and viability in the weedy check plots without herbicide application which indicated that the newly formed tubers of purple nutsedge readily sprouted, displaying no seasonal dormancy. The reduced regeneration observed in HSM treatments, similar to glyphosate under SSB, may be attributed to their mechanism of action in disrupting the ALS enzyme. This disruption results in a swift cessation of cell division and plant growth which might ultimately result in reduction in the regrowth of purple nutsedge (Rathika et al
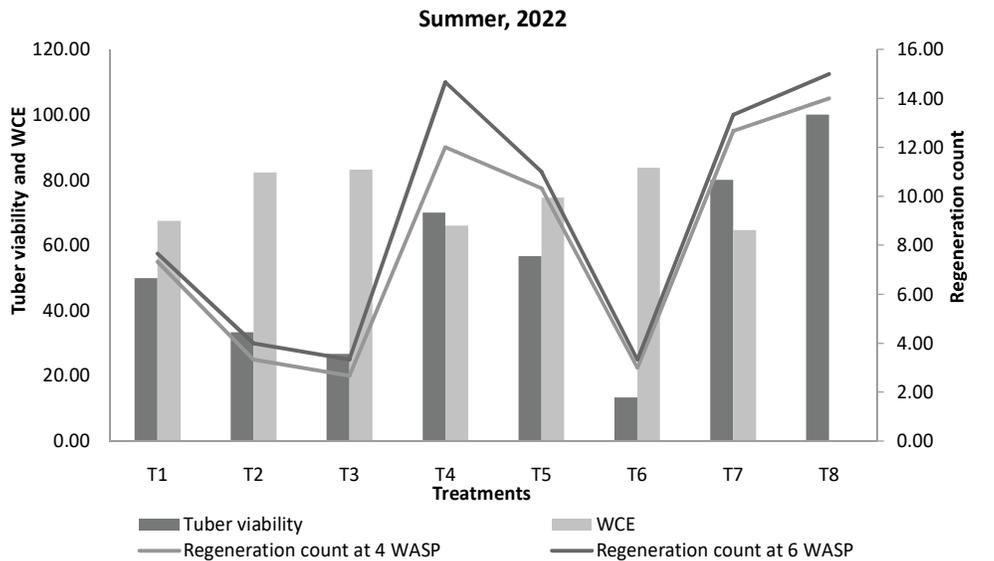

Fig. 1. Effect of different land preparation methods on tuber viability (%), WCE (%) and regeneration count of *Cyperus rotundus* L. during summer, 2022
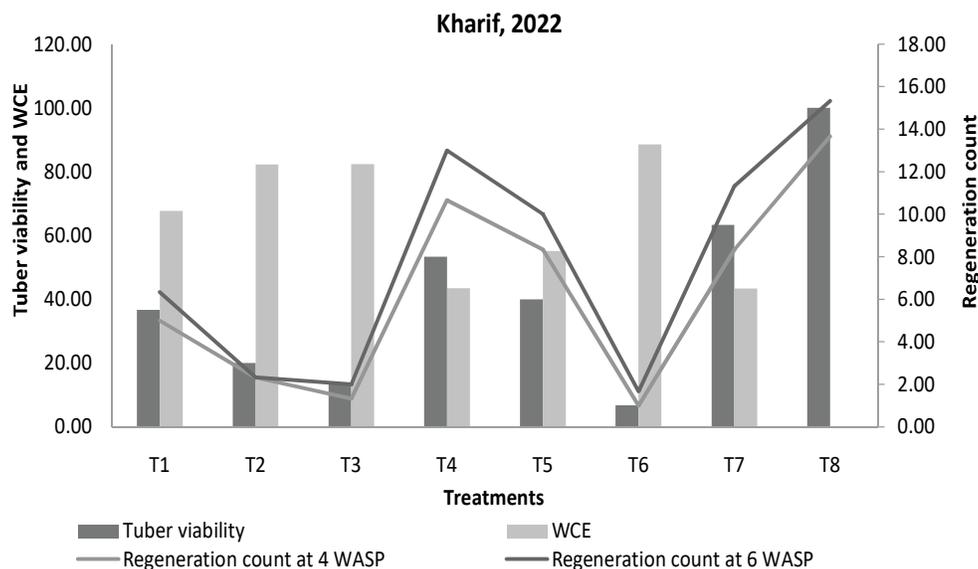

Fig. 2. Effect of different land preparation methods on tuber viability (%), WCE (%) and regeneration count of *Cyperus rotundus* L. during *kharif*, 2022

2013 and Desai et al 2017). Mathukia et al (2018) reported the most notable reduction in regrowth (5.76%) at 60 days after spraying through a tank-mix spray of glyphosate at 1230 g ha^{-1} combined with HSM at 33.75 g ha^{-1}, applied at 30 days after emergence (DAE). This outcome remained statistically comparable to the regrowth rates observed with HSM at 80 g ha^{-1} at 30 DAE (7.76%) and HSM at 67.5 g ha^{-1} at 30 DAE (8.48%).

CONCLUSION

The application of HSM at 67.5 g ha^{-1} applied at 3-4 leaf stage of purple nutsedge under stale seedbed method is equally effective as glyphosate at 1.5 kg ha^{-1} and could be effectively employed for exhausting tuber reserve of nutsedge with reduced tuber dry weight, tuber viability and regeneration. As glyphosate is under restricted use, HSM could be suggested as its substitute for nutsedge management in uplands.

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Management Strategies of Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] to Cope with Rainfall Anomalies under Semi-Arid Regions of Rajasthan

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Abstract: Field experiment was carried out at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, during *kharif* seasons of 2019 and 2020 to optimize pearl millet production in the face of rainfall irregularities. The experiment comprises two pearl millet varieties (RHB-173 and RHB-177), four transplanting shock preventing methods (No treatment, Triacontanol @ 0.25 ml/litre, Triacontanol @ 0.50 ml/litre and Leaf clipping) and three transplanting dates (15th-30th June, 1st-15th July and 16th-31st July). Pearl millet cultivar RHB-173 observed significant effect on growth and yield of pearl millet as compared to RHB-177. Among the transplanting shock preventing methods, triacontanol @ 0.25 ml/litre found better effect on growth and yield of pearl millet as compared to no treatment, triacontanol @ 0.50 ml/litre and leaf clipping. The appropriate date for pearl millet transplanting was noted 1st-15th July to encouraging growth and yield of pearl millet in contrast to 15th-30th June and 16th-31st July. The study indicated the pearl millet variety RHB-173 transplanted during 1st-5th July with seedling treatment triacontanol @ 0.25 ml/litre a promising strategy for improving pearl millet production.

Keywords: Growth, Pearl millet, Transplanting, Transplanting shock, Variety, Yield

Pearl millet is a main coarse grain grown as a rainfed crop on marginal soils with minimal input management and holds a prominent position in dryland agriculture and makes a substantial contribution to the food security of the nation due to its innate ability to escape drought and adaption to drier and less fertile conditions (Kumar et al 2024). The rainfall pattern of Rajasthan is extremely irregular and varies greatly from area to area as well as from year to year (Pingale et al 2014). It directly influences the agricultural practices, particularly planting date, which significantly affects crop production (Nwajei et al 2019).The regional rainfall data of the last few years reveals that the monsoon rain does not occur at traditional dates of onset, an increase in the frequency of heavy rains in one day (Mukherjee et al 2018), shifting of the peaks of monsoon rains towards July and an increase in pre-monsoon (May-June) rains (Deoli and Rana 2019). Kumar et al (2010) found a decrease in annual and monsoon rainfall while increasing in winter, pre and post-monsoon seasons across India.

The production season of pearl millet is generally from late May to September. However, acreage, production and productivity are solely determined by the occurrence of the monsoon and delayed monsoon does not leave scope for its significant cultivation as the crop is bound to suffer from terminal drought. If the rains fail or end early, farmers could need to re-sow, this can be risky as the season may not be long enough for the crop to reach maturity, and the harvests may be small or even fail. Postponements in the pearl millet sowing reduce grain yield significantly, the rate of decline ranged from 4-80 kg/day/ha under dryland conditions Framers can't afford to sacrifice pearl millet as substitute crops do not provide sufficient fodder for livestock under the traditional system of mixed farming. Therefore, raising an advanced nursery of prominent varieties and transplanting them at a suitable time alleviate the problem of patchy stands and replanting costs, this reduces the growing period in the field, thus providing an earlier harvest, ease up the problem of short-duration rainfall and providing an additional dimension to food security. Transplanting is a conventional approach in certain regions of Africa and Asia in pearl millet and sorghum cultivation; moreover to fill gaps after crops emerge and thinning or to compensate for a growth period that is too short for an entire crop cycle (Khairwal et al 1990, Oswald et al 2001). The benefits of this practice are better control of crop density and higher yields (Tinh et al 1993). Transplanting of seedlings increases the yield and conjointly compensates the yield losses due to delay sowing (Upadhyay et al 2001, Jan et al 2015).

Imposing transplanting time on a crop is one of the good agronomic options to sustain crop production. Timely

planting of crops typically ensures ample time for root development and vegetative growth for optimum harvesting of available soil nutrients and radiant energy (Akhtar et al 2007). The variations in phenology, growth andyield were observed due to alterations in planting time andgenotype variability under arid and semi-arid environments (Soler et al 2008).Transplanting damages seedling roots, causing in an imbalance between water absorption and transpiration. Consequently, the growth and development of seedlings temporarily stagnate. This phenomenon is termed as transplant shock. The extent and duration of transplant-shock injuries have an effect on crop growth and yield. Triacontanol produces stronger seedlings with a far better root system and eventually develops into vigorous plants that produce better yields and conjointly increases the rates of several biochemical and physiological processes (Naeem et al 2010). Clipping of leaves has alternative choices at transplantation, allowing the seedlings to recover from transplanting shock quicker than the non-clipped ones. Leaf clipping at transplanting does not immediately improve plant water status, but it may alleviate drought stress. It conjointly been reported that leaf clipping presumably removes transpiring biomass and conserves soil moisture.

Another most important criterion is introducing an appropriate high-yielding cultivar with an appropriate maturity duration that matches into a specific water availability period not solely minimizes the risks but also ends up in a net yield enhancement. Cultivars have been reported to behave differently with transplanting (Ullah et al 2017). Traditional varieties are generally considered to have low productivity when compared to high yielding varieties and hybrids, thus they are often neglected and even avoided in the mainstream of pearl millet production. Hence, there is an extensive need to screen out such kinds of cultivars which not only have the potential to increase yield but conjointly appropriate for transplanting.

MATERIAL AND METHODS

Experimental site and location: The experiment was conducted at Rajasthan Agricultural Research Institute, Durgapura, Jaipur (Rajasthan) during *kharif* seasons 2019 and 2020, respectively. Geographically this place is situated at 26°51' North latitude, 75°47' East longitudes and at altitudes of 390 m above mean sea level in Jaipur district of Rajasthan and region falls under Agro-climatic zone III-a (Semi-arid eastern plain zone) of Rajasthan.

Climate and weather conditions: The climate of this region is a typically semi-arid and experiences extremes of temperature during both in summers and winters. The average annual rainfall of this tract varies from 400 mm to 500

mm and 85 to 91%is received from June to September (*kharif* season) by the south west monsoon. The periodical mean weekly weather parameters during both the years of experimentation recorded from the meteorological observatory of Rajasthan Agricultural Research Institute, Durgapura, Jaipur (Fig. 1, 2). The mean daily maximum and minimum temperature fluctuated between 31 to 44.6°C and 21.6 to 30.1°C, and 30.4 to 40.9°C and 20 to 28.3°C during the crop growing seasons 2019 and 2020, respectively. There was rainfall of 748.2 mm and 518.6 mm during the 2019 and 2020, respectively during both the seasons. The evaporation data revealed that the weekly average evaporation varied from 14.2 to 1.7 and 10.3 to 2.5 mm/day during experimental seasons 2019 and 2020, respectively. The entire weather data indicated that the weather conditions were normal and favourable for the adequate growth and development of the pearl millet crop during the both *kharif* seasons of 2019 and 2020.

Treatments: The experiment comprises two pearl millet varieties *viz*., V$_1$- RHB-173 and V$_2$- RHB-177), four transplanting shock preventing methods *viz*., M$_0$- No treatment, M$_1$- Triacontanol @ 0.25 ml/litre, M$_2$- Triacontanol @ 0.50 ml/litre and M$_3$- Leaf clipping) and three dates of transplanting *viz*., D$_1$- 15th-30th June, D$_2$- 1st-5th July and D$_3$- 16th-31st July) replicated thrice in factorial randomized block design.

RESULT AND DISCUSSION
Growth Parameters and Grain Yield of Pearl Millet
Effect of varieties: The growth attributes *viz*. plant height, dry matter accumulation, number of tillers per plant, leaf area and grain yield of pearl millet, exhibited marked differences due to the varieties.Initially (20 DAT), both the pearl millet varieties did not vary significantly in their plant height and dry matter accumulation but at 40 DAT and at harvest, hybrid RHB-173 observed significantly taller plant and greater biomass as compared to RHB-177. The pearl millet variety RHB-173 also recorded significantly higher number of tillers per plant and maximum leaf area over RHB-177 at 20 and 40 DAT and at harvest. The improvement in these growth attributes might be due to more penetration of solar radiation and the hybrids have the inherent ability to utilize solar radiation efficiently owing to their larger photosynthetic area, which probably accounts for more photosynthesis to produce a higher number of tillers per plant, resulting in a greater accumulation of dry matter (Gupta et al 2016). The differences in the overall growth, development and grain yield of pearl millet varieties are mainly due to variation in their genetic make-up, weather conditions and agronomical assist supplied during the life cycle. The genetic potential of

cultivar RHB-173 permitted the transformation of higher energy into the formation of a number of yield determining traits shown to be profitable in improving the grain yield of pearl millet. Similar kinds of results were also reported by earlier scientists (Sharma et al 2013, Yadav et al 2014, Ullah et al 2017).

Effect of transplanting shock preventing methods: The growth parameter *i.e.* plant height, number of tillers, leaf area, and dry matter production observed at 20 days periodic intervals up to harvest and grain yield showed a significant improvement due to transplanting shock preventing methods

over no treatment during both the years of study and on the basis of pooled analysis.The different doses of triacontanol *i.e.* 0.25 and 0.50 ml/litre remained at par with each other to improve these growth attributes and grain yield, but above both doses proved significantly superior over leaf clipping and no treatment at all the crop growth stages at 20, 40 DAT and at harvest. Triacontanol, being a plant growth promoter, stimulates plant growth and the rate of several biochemical and physiological processes of various crops (Naeem et al 2010). Triacontanol alleviates the adverse effect of transplanting shock on crop growth during the recovery stage
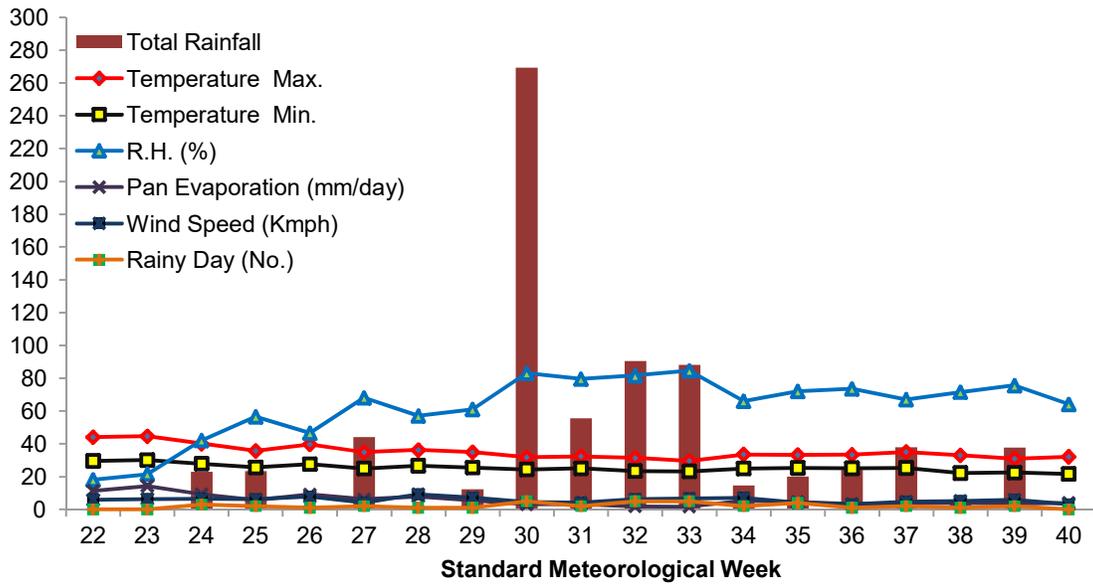

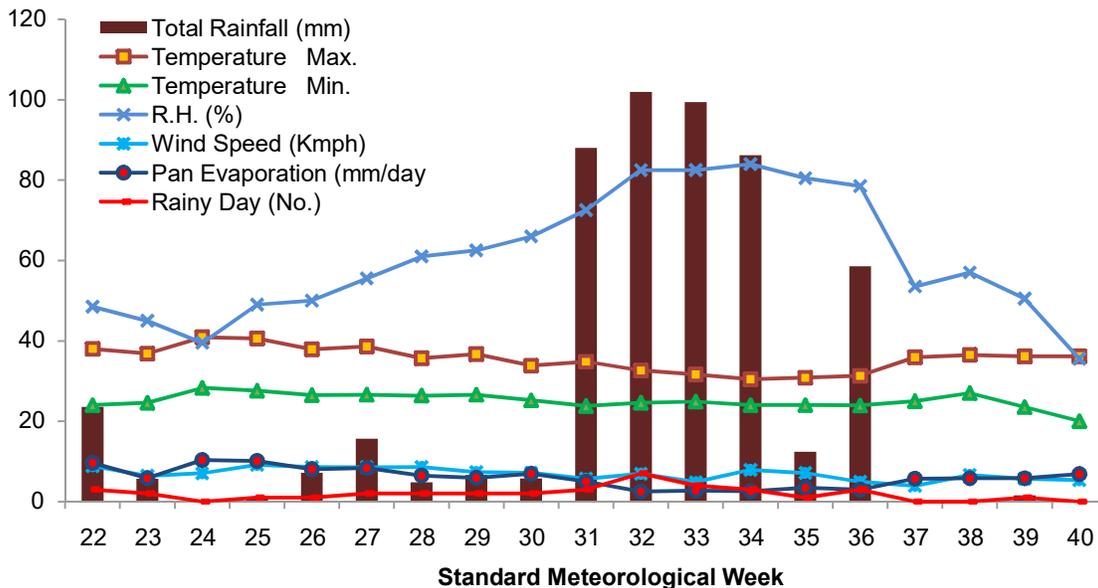**Fig. 1.** Mean weekly meteorological data during crop season (*Kharif,* 2019)

Fig. 2. Mean weekly meteorological data during crop season (*Kharif,* 2020)

of pear millet seedlings after transplanting. The increment in all growth parameters might be due to the synthesis of a higher amount of chlorophyll content and increased photosynthetic activity, CO_2 fixation rate, and greater translocation of photosynthates from sink to source. In addition to this, triacontanol increases water and nutrient uptake, which might be due to better development of roots, rapid cell division and cell elongation resulting in enhanced growth and development of the plant. Triacontanol alleviates transplanting shock and shortens the recovery period by regulating antioxidant enzymes and the redox states of ASA and GSH, resulting in less ROS damage due to increased photosynthetic efficiency with greater translocation of photosynthates towards the reproductive system and accumulation in the sink, and, ultimately, increased grain and stover yield (Li et al 2016, Khardia et al 2020). Leaf clipping at transplanting also promoted all the growth attributes as compared to no treatment during years of investigation. This might be due to removal of transpiring biomass from seedlings at transplanting helped to rapid recovery from transplanting shock and the crop's better withstand under water stress conditions as transpiration was checked through clipping of leaves, which resulted in the well establishment of seedlings and it leads to faster growth and development of plants and, ultimately, increased grain yield of pearl millet in comparison to non-clipped transplants. These results are in close conformity with the findings of Mapfumo et al (2007) in pearl millet and sorghum.

Effect of transplanting dates: The different transplanting dates revealed a significant influence on growth parameters such as plant height, dry matter accumulation, total tillers per plant, and leaf area at various physiological growth stages, as well as grain yield of pearl millet. The second date of transplanting (1st-15th July) had taller plants, higher biomass accumulation, a greater number of tillers, more leaf area, and grain yield than the first date of transplanting (15th-30th June), but the later date of transplanting had a similar growth pattern (16th-31st July). This could be because timely planting provides favourable climatic conditions, such as temperature, soil moisture, and longer sunshine hours, which stimulate the plants to increase their growth and development in comparison to early planting, resulting in higher grain yield. In contrast, all of these parameters were reversed in the early transplanted crop, resulting in lower values of these growth contributing traits and grain yield of pearl millet. This may be due to an unexpected moisture deficiency and high temperature during the initial crop growth stage, which hampered crop establishment. Comparable results were reported by Siddig et al (2013), Ullah et al (*2017*) and Londhe et al (2020).

Regression analysis: The regression equation predicted linear increment in the grain yield with a unit increase in the

Table 1. Effect of transplanting dates and shock preventing methods on plant height and dry matter accumulation of pearl millet varieties

Treatments	Plant height (cm)			Dry matter accumulation (g/m^2)		
	20 DAT	40 DAT	At harvest	20 DAT	40 DAT	At harvest
Varieties						
V_1	39.74	148.64	173.86	193.04	481.32	628.32
V_2	40.90	133.97	151.22	188.10	394.74	500.50
CD (p=0.05)	NS	4.10	4.47	NS	12.52	15.34
Transplanting shock preventing methods						
M_0	35.47	128.99	145.63	169.66	367.71	459.65
M_1	42.85	147.61	170.80	200.85	472.16	615.50
M_2	44.14	150.63	175.89	205.96	487.74	637.56
M_3	38.82	137.98	157.84	185.81	424.51	544.93
CD (p=0.05)	1.69	5.80	6.32	7.89	17.70	21.69
Dates of Transplanting						
D_1	37.90	134.15	150.34	176.02	390.97	498.44
D_2	42.14	146.95	170.99	200.10	468.74	607.34
D_3	40.93	142.81	166.29	195.58	454.38	587.46
CD (p=0.05)	1.47	5.03	5.47	6.83	15.33	18.79
CV (%)	8.97	8.77	8.31	8.87	8.63	8.21

NS= Non-significant

Table 2. Effect of transplanting dates and shock preventing methods on total number of tillers, leaf area and grain yield of pearl millet varieties

Treatments	Total number of tillers/plant			Leaf area (cm²/plant)			Grain yield (kg/ha)
	20 DAT	40 DAT	At harvest	20 DAT	40 DAT	At harvest	
Varieties							
V₁	2.74	3.63	3.66	945	2015	1955	2559
V₂	2.31	2.93	2.97	841	1816	1779	1873
CD (p=0.05)	0.07	0.09	0.10	22.6	59.2	52.9	59.4
Transplanting Shock Preventing Methods							
M₀	2.26	2.85	2.90	800	1613	1604	1896
M₁	2.65	3.47	3.53	939	2071	1997	2369
M₂	2.73	3.62	3.64	972	2111	2051	2452
M₃	2.47	3.17	3.19	861	1866	1815	2147
CD (p=0.05)	0.09	0.13	0.13	32.0	83.7	74.8	84.0
Dates of Transplanting							
D₁	2.31	2.96	2.99	845	1788	1703	1966
D₂	2.68	3.50	3.54	928	2009	1976	2376
D₃	2.59	3.37	3.42	906	1950	1921	2306
CD (p=0.05)	0.08	0.12	0.12	27.7	72.5	64.8	72.7
CV (%)	8.02	8.71	8.66	7.6	9.3	8.6	8.10

NS= Non-significant
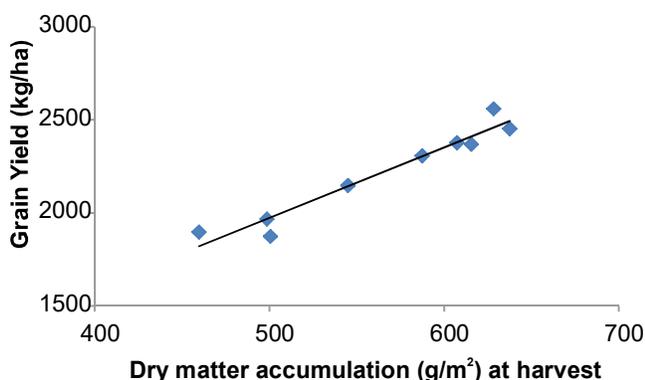
Fig. 3. Relationship between dry matter accumulation and grain yield of pearl millet

dry matter accumulation by crop (Fig. 3). It revealed that 1g/m² dry matter accumulation increased the grain yield by 3.78 kg/ha.

CONCLUSION

Pearl millet cultivar RHB-173 transplanted during the first 1st fortnight of July with a foliar spray of triacontanol @ 0.25 ml/litre prior to two days of transplanting in a pearl millet nursery as a shock preventing method recorded better crop growth and provided significantly higher grain yield.The research findings are useful for the farmers of semi-arid ecosystem of Rajasthan, where pearl millet growers suffers

badly due to delayed and uneven distribution of monsoon rains and resulted in patchy stand of crop. Due to transplanting technology of pearl millet, farmers will be able to raise pearl millet seedlings during the off season in nursery and able to transplant pearl millet in time.

AUTHORS CONTRIBUTION

The experiment was carried out and original manuscript draft prepared by VL Yadav. R Saxena: designed the methodology of experiment. L Verma: helped in field data collection, reviewing and editing manuscript. P Yadav: helped in statistical analysis, DL Kikraliya: preparation of figures. UN Shukla: contributed in research design, reviewing the final draft and editing.

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Effect of Green Manures, Biofertilizers and Vermicompost on Quality Parameters of Sapota [*Manilkara achras* (Mill.) Fosberg] cv. Kalipatti

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Abstract: Field experiment has been performed at Anand Agricultural University in Anand, Gujarat over the years 2019-20 and 2020-21, with ten treatments having components of green manures like sunhemp, dhaincha and cowpea, vermicompost, biofertilizer and microbial consortium. Organic fertilizers application has the potential to increase the biomass and productivity of a wide range of crops when used properly. Treatment 75% RDN from green manure of sun hemp + microbial consortium (AMBC I) 105 ml + 10 ml Anubhav Bio NPK consortium per tree gave the best results in terms of quality parameters compared to other treatments having a combination of green manure with dhaincha, cowpea, vermicompost and biofertilizers. The treatment also resulted in the highest total soluble solid (23.49 °Brix), reducing sugar content (6.08%), non-reducing sugar content (11.88%), total sugar content (17.96%), ascorbic acid content (21.48 mg/100g pulp) and shelf life (9.09 days) of the fruits in both years. Acidity content was also lowest (0.182%).

Sapota, also known as *Manilkara achras*, is a slow-growing tropical fruit tree belonging to the Sapotaceae family. It is a major fruit crop in India, Mexico, Guatemala and Venezuela. In India, sapota is cultivated across 89,000 hectares of land, producing a yield of 10.03 lakh MT and a productivity rate of 11.26 MT/ha (Anonymous 2019[a]). The states of Karnataka, Gujarat, Tamil Nadu, Maharashtra, and Andhra Pradesh are the primary sapota-producing regions in India. Gujarat alone cultivates sapota on 27,827 hectares, yielding 3,10,012 MT annually with a productivity rate of 11.14 MT per hectare (Anonymous 2019[b]). There is a growing demand for organic fruits both domestically and internationally, and growers are benefitting from exporting organic fruits to other countries with better prices. The farmers are interested in organic farming. green manuring crops and biofertilizers as most effective sources of nutrients in organic sapota farming. Organic manures supply plants with nutrients and micronutrients. Chimouriya et al (2018) suggested that green manure is a cost-effective and environmentally friendly alternative to agrochemicals. Patel et al in (2023) observed that the application of double green manuring of sunhemp in the canopy area along with the use of 10 ml Bio NPK consortium per tree can significantly improve quality parameters in Mango. Han et al (2022) found that the use of different green manures can improve the quality of pear fruit crops. Zhou et al (2022) observed that incorporating organic manure and reducing chemical fertilizer by 30% is a promising fertilizer management

strategy for sustainable productivity and environmental protection in citrus orchards. Very little research-based knowledge is available on the impact of organic fertilizers on sapota fruit quality and production parameters. Additionally, there is a lack of information on nutrient management through green manuring with bio-fertilizers and vermicompost in fruit crops. The current study was aimed to investigate the effect of different organic sources on the quality parameters of sapota [*Manilkara achras* (Mill.) Fosberg] cv. 'Kalipatti' on 22-year-old sapota trees.

MATERIAL AND METHODS

Field experiment was conducted at the Anand Agricultural University, Anand during 2019-20 and 2020-21. The experiment followed a completely randomized design with ten treatments, each consisting of a combination of different green manure, biofertilizer and vermicompost. [T_1: Control: 100 % RDF from chemical fertilizer (1000:500:500 g NPK) + 100 kg FYM per tree, T_2: 100% RDN from green manure of sun hemp + microbial consortium (AMBC I) 140 ml per tree, T_3: 100% RDN from green manure of cowpea + Microbial consortium (AMBC I) 150 ml per tree, T_4: 100% RDN from green manure of dhaincha + Microbial consortium (AMBC I) 160 ml per tree, T_5: 75% RDN from green manure of sun hemp + microbial consortium (AMBC I) 105 ml + 10 ml Anubhav Bio NPK consortium per tree, T_6: 75% RDN from green manure of cowpea + microbial consortium (AMBC I) 110 ml + 10 ml Anubhav Bio NPK consortium per tree, T_7:

75% RDN from green manure of dhaincha + microbial consortium (AMBC I) 120 ml + 10 ml Anubhav Bio NPK consortium per tree, T_8: 50% RDN from vermicompost + 50% RDN from green manure of sun hemp + microbial consortium (AMBC I) 100 ml per tree, T_9: 50% RDN from vermicompost + 50% RDN from green manure of cowpea + microbial consortium (AMBC I) 105 ml per tree, T_{10}:50% RDN from vermicompost + 50% RDN from green manure of dhaincha + microbial consortium (AMBC I) 110 ml per tree] and was replicated thrice. The green manuring crops were sown separately in another field. Cowpea was sown using the line sowing method, while dhaincha and sun hemp were broadcasted. Sowing was done after 15 June for both years as green manures grow well in rainy season. The green manures were applied in the form of green biomass of sunhemp, cowpea and dhaincha. The green manures were applied in quantities respective to the treatment requirements according to the recommended dose of nitrogen applied in mature sapota trees which was 1000g. Sun hemp and dhaincha were analyzed for nitrogen content at 50 days after sowing while cowpea at 40 days after sowing in both the seasons 9 (Table 1). The required amount of green manure was applied in a ring around the tree's base during the first week of August for both years. Tillage was performed using a rotavator around the tree's canopy after applying the green manure.

In both years, biofertilizer was applied 7 days after the green manure application. A mixture of 10 ml of Bio-NPK consortium was dissolved in 20 litres of water and applied by creating rings around the trees, positioned 1-1.5 meters away from the main trunk. Ten fruits were selected from each replication as per treatments at the time of the third harvest i.e., in April at a mature stage for analysing different quality parameters. To measure the TSS of ripe fruit pulp, a digital pocket hand refractometer with a range of 0-32 °Brix was used. The acidity, total sugar, reducing sugar, non-reducing sugar and ascorbic acid were also measured using the methods outlined by Ranganna (1979). The shelf life of the fruit was determined by keeping five mature fruits at the third harvest i.e., in the month of April under ambient temperature in the laboratory and observing every day up to the deterioration of the fruits. Statistical analysis was conducted on yearly data of various parameters.

RESULTS AND DISCUSSION

Treatment T_5 with 75% sunhemp, has an adequate amount of nitrogen content. Compared to other treatments, easily decomposes with the use of a microbial decomposer. This treatment can be used as a biofertilizer and promotes the growth of plants directly or indirectly by providing nutrition. In T_5, 75% RDN from green manure of sun hemp +105 ml of microbial consortium (AMBC I) + 10 ml of Anubhav Bio NPK consortium per tree, had the highest total soluble solid 23.49 °Brix. This might be due to the application of green manure with sun hemp and biofertilizers increasing the availability of nutrients, improving soil aeration, stimulating cell division, cell elongation, and better translocation of water uptake and deposition of nutrients, which leads to an increase in dry matter and total soluble solids of the fruits. Kumar et al. (2017) also observed significant improvements in mango cultivation when utilizing green manure from sun hemp, combined with farmyard manure and NPK. The application of double green manuring of sunhemp with 10 ml Bio NPK consortium per tree enhances significantly quality parameters in mango cv. Amarapali (Patel et al 2023). Similarly, Dey et al (2005) reported positive effects on guava growth with the use of 200 g of phosphate solubilizers (PSB) per plant annually. Sau et al (2017) observed better growth with the use of biofertilizers (*Azotobacter chorococcum* + *Azospirillum* brasilense + AM (*Glomus musseae*) + Panchagavya 3%) in mango cultivation.

Table 1. Nitrogen content (%) of green manures

Organic fertilizers	N content (%)	
	2019-20	2020-21
Sunhemp	0.71	0.67
Cowpea	0.67	0.60
Dhaincha	0.62	0.64

Table 2. Quantity of green manures applied with respective treatments

Treatment	Quantity (kg/tree)	
	2019-20	2020-21
100% RDN from green manure of sun hemp	140.84	149.25
100% RDN from green manure of cowpea	149.25	166.66
100% RDN from green manure of dhaincha	161.29	156.25
75% RDN from green manure of sun hemp	105.63	111.94
75% RDN from green manure of cowpea	111.94	125.00
75% RDN from green manure of dhaincha	120.96	117.18
50% RDN from green manure of sun hemp	70.42	74.62
50% RDN from green manure of cowpea	74.62	83.33
50% RDN from green manure of dhaincha	80.64	78.12

The maximum reducing sugar 6.08 % was observed in the application of a treatment, T_5. This might be due to the application of sun hemp as green manure with bio fertilizers increasing the uptake and translocation of nutrients which leads to the increase in the photosynthetic ability and carbohydrate supply which increases the dry matter and sugar content of the fruits. Shukla et al (2009) found that guava plants responded well to a treatment of 50% recommended doses of NPK, along with 50 kg of FYM and 250 g of *Azotobacter* per plant. Singh and Varu (2013) recorded improvements in papaya growth with half-dose RDF, along with 50 g of *Azotobacter* per plant and 2.5 g of PSB per square meter. Lodaya and Masu (2019) also observed better growth in guava with soil application of 30% RDF through chemical fertilizers, 30% RDN through poultry manure and 20 ml of Bio NPK Consortium per tree. The treatment T_5 also recorded significantly higher non-reducing sugar 11.88 % in pooled data. Data presented in Table 1.3 revealed that an interaction of year and treatments (Y x T) effect on non-reducing sugar (%) was noted as non-significant. This could be attributed to the application of green manuring with sun hemp with bio-fertilizers, which increases nutrient uptake and translocation, increasing photosynthetic ability and carbohydrate supply, which might increase the dry matter and sugar content of the fruits. Parallel results were

found by Singh and Varu (2013) in papaya with the application of half-dose RDF + Azotobacter @ 50 g/plant + PSB @ 2.5 g/m^2 and Sharma et al. (2016) in mango with an application of vermicompost (25 kg/plant) + Oil cake (2.5 kg/plant) + *Azotobacter* + VAM + *Trichoderma viridi* + PSB @ 100g/plant.

The T_5 treatment resulted in the highest total sugar levels of 17.96%. The interaction of treatments (Y x T) effect on total sugar (%) was significant. The cumulative effect of different treatments on building up the sugar content was observed. This might be due to the application of sun hemp as green manure improving soil nutrient status and bio-fertilizers making them available to the plants and helping them with uptake and translocation of the nutrients, which led to the increase in dry matter accumulation and total sugar content of the fruits. Similar trend was observed by Khachi et al (2015 in kiwifruit vines using sun hemp as green leaf manure. T_5 treatment had the highest amount of ascorbic acid 21.48 mg/100 g pulp. This might be due to the application of green manuring with sun hemp and biofertilizers increasing the availability, uptake and translocation of plant nutrients, especially nitrogen, which might lead to the synthesis of organic acids in fruits, increasing ascorbic acid content in fruits. The trend was observed by Kumar et al (2017) in mango with use of sun

Table 3. Effect of green manures, biofertilizers and vermicompost on the quality parameters of sapota [*Manilkara achras* (Mill.) Fosberg] cv. 'Kalipatti'

Treatment	Total soluble solids (^{0}Brix)	Reducing sugar (%)	Non-reducing sugar (%)	Total sugar (%)	Ascorbic acid (mg/100 g pulp)	Acidity (%)	Shelf life of fruits (days)
Pooled data (2019-20 and 2020-21)							
T_1	19.44	4.34	9.63	13.98	18.86	0.232	6.90
T_2	21.26	5.23	10.79	16.15	20.07	0.217	8.11
T_3	20.96	5.10	10.64	16.30	19.98	0.221	7.68
T_4	19.94	4.63	10.09	14.72	19.05	0.224	7.12
T_5	23.49	6.08	11.88	17.96	21.48	0.182	9.09
T_6	22.28	5.66	11.20	16.86	20.41	0.202	8.31
T_7	20.33	4.83	10.40	15.23	19.52	0.223	7.36
T_8	22.81	5.90	11.61	17.51	21.17	0.187	8.96
T_9	22.46	5.72	11.39	17.11	20.82	0.200	8.59
T_{10}	21.86	5.57	10.97	16.54	20.65	0.210	8.25
CD (p =0.05)							
(T)	0.41	0.49	0.41	0.32	0.57	0.007	0.19
(Y)	0.18	NS	NS	0.14	NS	0.003	0.09
(Y x T)	NS	NS	NS	0.46	NS	NS	NS
C.V. %	1.63	7.99	3.29	1.69	2.44	3.07	2.04

Application of green manures

Covering of green manure with soil

Incorporation through Rotavator

Final view of plant

Plate 1. Cultural practices sapota [*Manilkara Achras* (Mill.) Fosberg] cv. Kalipatti

hemp green manure along with farm yard manure and NPK. Kundu et al (2011) observed that mango plants treated with 100% NPK + Azotobacter + VAM (98.1 kg/plant) also showed positive results. The interaction of year and treatments (Y x T) on ascorbic acid was non-significant.

The acidity (%) of sapota cv. Kalipatti can be greatly affected by various treatments using organic sources, as shown in Table 3. Treatment T_5 consistently resulted in the lowest acidity levels of 0.182% in the pooled data, which was at par with treatment T_8 (0.187 %). A perusal of data revealed that an interaction of year and treatments (Y x T) effect on acidity (%) was non-significant. This might be due to the greater availability of dry matter for sugar conservation due to the application of sun hemp as green manure and biofertilizers. The findings of Dutta et al (2010) showed that treating papaya with Azotobacter + Azospirillum + VAM + 2 kg FYM yielded positive results. Similarly, Singh et al (2014) found that applying FYM + Azotobacter + VAM to Aonla was effective.

The effect of various organic treatments on the shelf life (days) of sapota cv. Kalipatti in both years of the study, as well as their pooled analysis, are shown in Table 3. It was observed that among different treatments T_5 had significant maximum shelf life 9.09 days in pooled results. Statistical perusal of data revealed that an interaction of year and treatments (Y x T) effect on acidity (%) was non-significant. It might be because green manure as sun hemp and biofertilizers increase the availability and uptake of plant nutrients which increases fruit quality and shelf-life of fruits. Patel et al (2017) discovered comparable outcomes in

sapota when 75% NPK + 15 kg vermicompost + 10 ml/tree AAU Bio NPK was applied, while Lodaya and Masu (2019) found similar results in guava with a soil application of 30% RDF through chemical fertilisers + 30% RDN through poultry manure + 20 ml Bio NPK Consortium per tree.

CONCLUSION

The quality parameters of sapota fruit can be be improved by using 75% RDN from sun hemp green manure and a microbial consortium (AMBC I) of 105 ml, along with 10 ml of Anubhav Bio NPK consortium per tree . These results can be helpful for further research on organic methods for increasing fruit production, as well as for farmers who wish to transition to organic farming for their fruit cultivation.

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Influence of Fertigation on Growth and Yield using Varying Rates and Sources of Fertilizers on Chilli Hybrid in Open Field Condition

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Abstract: The experiment was conducted to study the effect of fertigation on the performance of chilli F_1 Hybrid 'Arka Khyati' at the ICAR-Indian Institute of Horticultural Research, Bengaluru during *kharif* of 2017 and 2018. Ten treatments comprising of varying doses, sources and frequency of fertilizer application were laid out in Randomized Block Design and replicated thrice. Pooled analysis of two years' data revealed that at 80 days after transplanting, bi-weekly fertigation @ 125:100:125 kg N: P_2O_5:K_2O ha^{-1} using water soluble fertilizers resulted in highest values for plant height (78.78 cm) and number of branches plant^{-1} (10.88). This treatment also recorded maximum values for number of fruits plant^{-1} (132.00), fruit length (9.76 cm), fruit girth (3.95 cm), ten fruit fresh weight (66.00 g), ten fruit dry weight (10.60 g) and yield (34.00 t ha^{-1}). All the fertigation treatments recorded higher yields over the conventional soil application of fertilizers to the tune of 3.63 to 76.6 per cent. Biweekly application of 100 % fertilizer dose of 125:100:125 kg N: P_2O_5:K_2O ha^{-1} through fertigation resulted in the maximum net income (Rs. 431351 ha^{-1}) and higher benefit cost ratio (1.73) whereas the conventional soil application of common fertilizers resulted in minimum net income (Rs.166454 hectare^{-1}) and benefit cost ratio of 0.76.

Keywords: Chilli, fertigation, Growth, Nutrient sources, Nutrient doses, Yield, Economics

Chilli (*Capsicum annuum* L.), belonging to the solanaceae family is an important spice crop in India. The Green chilli is grown in 4.18 lakh hectares with the production of 44.17 lakh tonnes. The productivity of green chilli is approximately 10.60 t ha^{-1} in India, which is low (Anonymous 2021). The states like Andhra Pradesh, Karnataka, Bihar, Tamil Nadu, Uttar Pradesh and Maharashtra, account for three fourth of the total area. Fresh green and ripe chilli are used in flavouring of food, to make pickles, sauces and paste., Oleoresin, the essential oil is used in the food and beverage industries. The fruits of chilli are rich in vitamin A, C and minerals.

Chilli is one of the major commercial crops, however the productivity is low. Increase in production can be achieved either by bringing more area under its cultivation or by adopting improved varieties and better cultural practices. The second approach is more often preferred and practical among various cultural practices, proper fertilizer application is one of the quickest and easiest ways of increasing the yield per unit area (Natsheh and Mousa 2014). Balanced nutrition is one of the most important factors affecting the growth and productivity of the crops. The optimum levels at which the nutrients are to be applied, the placement of fertilizers and source from which they are derived are equally important to crop production as it affects the yield and quality of the produce. Fertigation is an effective means of controlling

timing and placement of fertilizers and improving fertilizer use efficiency by reducing losses through leaching, volatilization and fixation in the soil to less available forms as described by Papadopoulous (1994). Hence, this experiment was conducted to study the influence of fertigation, its frequency and the source of nutrients on yield of green chilli.

MATERIAL AND METHODS

The study was conducted at the ICAR-Indian Institute of Horticultural Research, Hessarghatta, Bengaluru, Karnataka, India during *kharif* of 2017 and 2018.The experimental field is situated at 13°7' N latitude, 72°29'E longitude and an elevation of 890 meters above mean sea level. The soil was well drained sandy loam (pH 6.60 and electrical conductivity 0.25 dSm^{-1}) characterized by medium organic carbon (0.63%), low available N (169 kg ha^{-1}), high available P (68 kg ha^{-1}) and medium available K (260 kg ha^{-1}). The soil has available water holding capacity of 130 mm in one meter soil depth. The experiment was laid out in Randomized Block Design with ten treatments and three replications. Prior to planting, uniform amount of farm yard manure @ 25.0 t ha^{-1} was applied as basal application to all the treatments. The treatment details and quantity of different fertilizers applied have been presented in Table 1 and Table 2, respectively. The entire dose of P and half of N and K were applied as basal and remaining half of N and K was side

dressed to soil in equal splits at 30 and 60 days after transplanting in T_1. Thirty-five days old seedlings of chilli hybrid "Arka Khyati" a high yielding, medium pungent, tolerant to chilli venial mottle virus cultivar were transplanted at 80-40 x 50 cm, under paired row system in the first week of July during both the years. Drip irrigation was given depending on the rate of evaporation and amount of effective rainfall received. Fertigation treatments started after two weeks of planting and fertilizers were applied through drip system at weekly and bi-weekly interval and imposed. Dissolving desired amounts of fertilizers and applied via venturi system through drip irrigation to the field. A total of 16 and 32 numbers of fertigation were given for weekly and bi-weekly interval, which was continued up to 15 days before completion of crop growth period. Recommended package of practices including agronomic and plant protection measures were adopted to raise the crop (Prabhakar *et al*.,2010). The

experimental data was statistically analysed (Gomez and Gomez,1983) and compared using critical difference at five per cent probability level. Statistical analysis was done using OPSTAT, HAU, Hisar developed by Sheron (1998).

RESULTS AND DISCUSSION

Growth parameters: Significant differences among the treatments for the plant height were observed at 80 days after transplanting and harvest (Table 3). Application of 100 per cent fertilizer dose through fertigation using water soluble fertilizers at bi-weekly interval (T_7) recorded significantly taller plants at 80 DAT (78.78 cm) and at harvest (96.33 cm), which was on par with T_9 (76.89 cm), T_4 (78.33 cm) and T_3 (78.70 cm) at 80 DAT and T_9 (92.00 cm), T_5 (90.33 cm) and T_3 (92.33 cm) at harvest. The minimum values for plant height (71.67 and 80.00 cm) at 80 days after transplanting and at harvest, respectively was recorded with soil application of nutrients

Table 1. Treatment details in chilli

Treatment		Fertilizer	Application dose	Basal dose (Kg ha^{-1})	Top dressing (Kg ha^{-1})	Fertigation (Kg ha^{-1})	Frequency
T_1	100 % fertilizer dose (125:100:125 Kg N:P$_2$O$_5$:K$_2$O ha^{-1})	Common	100 % soil application	62.5:100:62.5	62.5:0:62.5		
T_2		Common	50 % NK fertigation	62.5:100:62.5		62.5:0:62.5	
T_3		WSF	100 % NPK fertigation			125:100:125	Weekly
T_4		WSF	50 % NK fertigation	62.5:100:62.5		62.5:0:62.5	Weekly
T_5	75 % fertilizer dose (93.75:75:93.75 Kg N:P$_2$O$_5$:K$_2$O ha^{-1})	WSF	100 % NPK fertigation			93.75:100:93.75	Weekly
T_6		WSF	50 % NK fertigation	46.8:75:46.8		46.8:0:46.8	Weekly
T_7	100 % fertilizer dose (125:100:125 Kg N:P$_2$O$_5$:K$_2$O ha^{-1})	WSF	100 % NPK fertigation			125:100:125	Bi-weekly
T_8		WSF	50 % NK fertigation	62.5:100:62.5		62.5:0:62.5	Bi-weekly
T_9	75 % fertilizer dose (93.75:75:93.75 Kg N:P$_2$O$_5$:K$_2$O ha^{-1})	WSF	100 % NPK fertigation			93.75:100:93.75	Bi-weekly
T_{10}		WSF	50 % NK fertigation	46.8:75:46.8		46.8:0:46.8	Bi-weekly

WSF: Water soluble fertilizers   Top dressing - (Kg ha^{-1}): 62.5:0:62.5

Table 2. Treatment wise fertilizers applied (Kg ha^{-1}) under fertigation in chilli

Treatments	Basal dose			Fertigation			
	Urea	Single super phosphate	Muriate of potash	Urea	Muriate of potash	Sulphate of potash	19:19:19
T_1	135.5	625.0	104.5	0.00	0.00	0.00	0.00
T_2	135.5	625.0	104.5	135.5	104.5		
T_3	0.0	0.0	0.0	54.00		50.00	526.00
T_4	135.5	625.0	104.0	135.5		125.00	
T_5	0.0	0.0	0.0	40.50		37.50	394.00
T_6	102.00	469.0	78.00	102.00		94.00	
T_7	0.0	0.0	0.0	54.00		50.00	526.00
T_8	135.5	625.0	104.0	135.5		125.00	
T_9	0.0	0.0	0.0	40.50		37.50	394.00
T_{10}	102.00	469.0	78.00	102.00		94.00	

In T_1= Top dressing - (Kg ha^{-1}): Urea -135.5 and Muriate of potash -104.5

through common fertilizers. There were no significant differences for plant height at initial stage of the growth (35DAT). However, T_7 (59.11 cm) and T_4 (54.66 cm) recorded the maximum and minimum plant height. Different treatments recorded significant differences for the number of branches plant^{-1} at different growth stages. Application of 100 per cent fertilizer dose through fertigation using common fertilizers at weekly interval (T_2) recorded higher number of branches plant^{-1} (9.77) at 35 DAT, while application of 100 per cent fertilizer dose through fertigation using water soluble fertilizers at bi-weekly interval (T_7) recorded higher number of branches plant^{-1} (10.88) at 80 DAT, which remained on par with T_2, T_5 and T_9. At harvest T_7 and T_2 (11.33) recorded significantly higher number of branches plant^{-1} than T_1 (9.0) and T_{10} (9.33) and remained on par with remaining

treatments. Application of higher dosage of water soluble fertilizers through fertigation gave best results in growth parameters like plant height and number of branches plant^{-1}, which might be due to availability of higher amount of nutrients in the root zone for growth and development of plants as nitrogen and phosphorus are considered as major nutrients required for proper growth and development of plant. Beside this, nitrogen is the main constituent of protoplasm, cell nucleus, amino acids, chlorophyll and many other metabolic processes like transpiration, Godara et al (2013). Similar results were also reported by Pandey et al (2013), Vinayak et al (2019) and Chandramohan Reddy et al (2016) in chilli crop.

Yield attributes: Yield and yield attributing parameters were significantly influenced by the treatments (Table 4). Higher

Table 3. Growth parameters of chilli as influenced by fertigation treatments (Pooled data)

Treatment	Plant height (cm)			Branches plant^{-1}		
	35 DAT	80 DAT	At harvest	35 DAT	80 DAT	At harvest
T_1	55.22	71.67	80.00	6.77	8.33	9.00
T_2	56.66	73.99	81.67	9.77	10.11	11.33
T_3	58.66	78.70	92.33	6.88	7.89	9.67
T_4	54.66	78.33	87.67	7.55	8.44	9.67
T_5	57.11	74.11	90.33	8.11	9.66	10.00
T_6	57.22	70.00	84.00	7.89	8.99	10.33
T_7	59.11	78.78	96.33	9.33	10.88	11.33
T_8	57.33	74.33	87.00	7.11	8.77	9.67
T_9	58.77	76.89	92.00	9.33	9.44	10.67
T_{10}	56.00	73.77	84.67	8.33	8.55	9.33
CD (p=0.05)	NS	4.32	6.84	1.45	1.68	1.79

DAT – days after transplanting

Table 4. Effect of fertigation treatments on yield attributing characters, yield and FUE in chilli (Pooled data)

Treatment	Number of fruits plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Ten fruit weight (g)	Dry weight of ten fruits (g)	Yield (t ha^{-1})	Fertiliser use efficiency (kg kg^{-1})
T_1	82.67	8.22	3.66	30.33	7.83	19.25	55.00
T_2	84.50	8.71	3.58	33.33	8.50	19.95	57.00
T_3	118.17	9.73	3.81	64.67	9.80	32.71	93.45
T_4	107.33	9.00	3.48	33.33	8.83	22.19	63.40
T_5	110.67	9.58	3.43	54.67	9.13	29.93	114.00
T_6	92.50	8.62	3.55	42.67	8.50	21.36	81.37
T_7	132.00	9.76	3.95	66.00	10.60	34.00	97.14
T_8	109.67	9.07	3.72	35.33	8.96	29.79	85.11
T_9	111.83	9.76	3.81	59.33	9.46	32.46	123.65
T_{10}	105.17	8.63	3.53	35.33	8.76	22.74	86.62
CD (p=0.05)	22.98	1.07	0.29	21.86	0.74	5.31	

number of fruits plant^{-1} was observed in T$_7$ (132.00), which remained on par with T$_8$ (109.67), T$_5$ (110.67), T$_9$ (111.83) and T$_3$ (118.17). The minimum number of fruits plant^{-1}was recorded with T$_1$ (82.67). Higher availability of soil moisture, optimum NPK nutrients and uptake when supplied through fertigation might have increased the number of fruits per plant. Fertigation leading to better availability of the nutrients might have increased the number of primary branches, shoot growth and thereby potential sites where flower could develop. Similar results were also reported by Prabhakar et al (2010), Ramachandrappa et al (2010), Krishnamoorthy and Noorjehan (2014) and Chandramohan Reddy et al (2016) in chilli crop. Significantly higher values for fruit length (9.76 cm) was also observed in T$_7$ and T$_9$, which remained on par with most of the treatments except T$_1$(8.22 cm), T$_6$ (8.62 cm) and T$_{10}$(8.63 cm).As far as fruit girth was concerned the significantly highest fruit girth was recorded in T$_7$ (3.95 cm), which remained on par with T$_3$ and T$_9$ (3.81 cm), T$_8$ (3.72 cm) and T$_1$ (3.66 cm). T$_5$ recorded the minimum (3.43 cm) value for the fruit girth. Similarly, there were significant differences among the treatments for ten fruit weight and T$_7$ resulted in significantly higher value (66.00 g) than all other treatments except T$_5$ (54.67 g), T$_9$ (59.33 g) and T$_3$ (64.67 g). The minimum value for ten fruit weight was recorded with T$_1$ (30.33 g). Bi-weekly application of 100 per cent fertilizer dose through fertigation using water soluble fertilizers (T$_7$) resulted in significantly higher (10.60 g) dry weight of ten fruits than all other treatments. Weekly application of same amount of fertilizers through fertigation (T$_3$) recorded the second highest value (9.80 g) followed by T$_9$ (9.46 g). The minimum value (7.83 g) for the same recorded with soil application of nutrients. This may be due to continues nutrient supplied through fertigation in adequate doses and optimum form, which must have helped in healthy growth of plants and increased the fruit length and girth. The present findings are in accordance with the findings of Paul *et al.* (2013) in capsicum, Ramachandrappa et al (2010), Krishnamoorthy and Noorjehan (2014) and Vinayak et al (2019) in chilli.

Yield: Irrespective of dosage and source of fertilizer, fertigation treatments were superior to conventional soil application treatment with respect to yield. Among the fertigation treatments (Table 4), bi-weekly application of 100 per cent fertilizer dose through fertigation using water soluble fertilizers (T$_7$) resulted in significantly higher yield (34.00 t ha^{-1}) over all the other treatments except the treatment T$_3$, where the weekly application of same amount of fertilizer was given through the same sources (32.71 t ha^{-1}), T$_9$ (32.46 t ha^{1}), T$_5$ (29.93 t ha^{1}) and T$_8$ (29.79 t ha^{-1}). All the fertigation treatments recorded higher yields over the conventional soil application

of fertilizers to the tune of 3.63 to 76.6 per cent. Reducing the dosage of NK or NPK fertigation by 25 per cent reduced the yield substantially. This can be explained on the basis that fertigation saves fertilizer inputs as it permits applying fertilizers in small quantity at a time coinciding with the plants nutrient need. This contributes to an improved availability of moisture, nutrients, and uniform distribution of fertigated nutrients in the crop root zone throughout the growth stages leading to better uptake of nutrients. The enhancing effects of NPK on vegetative growth might be attributed to their vital contribution in several metabolic process in plants related to growth (Marschner 1986). It stimulates the plant vegetative growth to generate leaves, which are able to produce photosynthetic products accumulation required for fruits formation and development and subsequently fruit yield and its attributes. Gireesh et al (2020) and Vinayak et al (2019) reported the same results in chilli crop.

Fertilizer use efficiency: The fertilizer use efficiency ranged between 55.00 to 123.65 kg kg^{-1} for the fertigation treatments (Table 4).Though application of 100 per cent fertilizer dose using water soluble fertilizers at bi-weekly interval (T$_7$) recorded the highest yield of 34.00 t ha^{-1} but the fertilizer use efficiency was highest (123.65 kg kg^{-1}) with the treatments where the 75 per cent of fertilizer dose was given through fertigation using water soluble fertilizers at bi-weekly intervals. It was followed by T$_5$ (114.00 kg kg^{-1}), T$_7$ (97.14 kg kg^{-1}) and T$_3$ (93.45 kg kg^{-1}). The minimum fertilizer use efficiency was recorded in soil application of common fertilizers (55.00 kg kg^{-1}). Ramachandrappa et al (2010) also recorded higher fertilizer use efficiency at 75% recommended dose of NPK through fertigation than 100 per cent recommended NPK fertigation in green chilli.

Economics: The average data pertaining to economic returns and benefit: cost ratio related to 'Arka Khyati' a chilli hybrid for the year 2017 and 2018 are given in Table 5. All the fertigation treatments with water soluble fertilizers resulted in higher gross income than soil application (T$_1$) and fertigation with common fertilizers (T$_2$). Among the fertigation treatments, application of 100 per cent fertilizer dose through fertigation on bi-weekly basis (T$_7$) has resulted in highest gross and net income (Rs. 680000 ha^{-1} and Rs. 431351 ha^{-1}) followed by T$_3$ *i.e.* same amount of fertilizer given on weekly basis (Rs. 654200 ha^{-1} and Rs. 405551 ha^{-1}). Irrespective of dosage and frequency, fertigation with water soluble fertilizers resulted in higher B:C ratio (0.94 to 1.73) compared to soil application (0.76). Krishnamoorthy and Noorjehan (2014). Gireesh et al (2020), Chand (2014) and Suman Kumari et al (2020) also reported maximum net returns and benefit: cost ratio with the application of 100% recommended dose of NPK through fertifgation.

Table 5. Economics of green chilli crop in relation to fertigation treatments

Treatment	Average yield (t ha^{-1})	Gross investment (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B :C ratio
T_1	19.25	218546	385000	166454	0.76
T_2	19.95	218546	399000	180454	0.82
T_3	32.71	248649	654200	405551	1.63
T_4	22.19	224199	443800	219601	0.98
T_5	29.93	238419	598600	360181	1.51
T_6	21.36	220150	427200	207050	0.94
T_7	34.00	248649	680000	431351	1.73
T_8	29.79	224199	595800	371601	1.65
T_9	32.46	238419	649200	410781	1.72
T_{10}	22.74	220150	454800	234650	1.06

Sale price = Rs. 20.00/kg

CONCLUSION

The application of water soluble fertilizers @125:100:125kg N:P_2O_5:K_2O ha^{-1} during the cropping period through fertigation at bi-weekly intervals resulted in higher yield (34.00 t ha^{-1}), net income of (Rs. 431351 ha^{-1}) and B:C ratio (1.73) in *kharif* grown chilli in red sandy loam soils.

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Effect of Bioinoculants and Plant Growth Regulators on Germination and Seedling Growth of Wild Ber (*Ziziphus rotundifolia* Lamk.) under *in-vitro* Conditions

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Abstract: The prime motive of this experiment was to investigate the effectiveness of bioinoculants and plant growth regulators (PGRs) in improving the germination rate and seedling growth of wild ber seeds under *in-vitro* conditions. The experiment was conducted at the Department of SST, CCSHAU, Hisar, India, during the 2021-22 season. The seeds removed from stone were treated with five bioinoculants *viz*, Azoteeka- Mac 27, Azoteeka- HT 54, Phosphoteeka- P36, *Azospirillum*-J11-12 and integrated biofertilizer (NPK- 1:1:1) by soaking for 30 min and dipped in six-plant growth regulators (PGRs) *viz.*, 50 mg/L gibberellic acid (GA$_3$), 100 mg/L GA$_3$, 50 mg/L 1-naphthalene acetic acid (NAA), 100 mg/L NAA, 50 mg/L indole-3-butyric acid (IBA), 100 mg/L IBA for 24 hrs and control. Among different treatments under laboratory conditions, maximum seed viability, maximum germination percentage, maximum vigour indices [vigour index- I, vigour index- II] and the least mean germination time were recorded when seeds were treated with GA$_3$ @100 mg/L for 24 hrs. Among different bioinoculant treatments, the seed treated with integrated biofertilizer (NPK- 1:1:1) for 30 min led to the highest seedling length, maximum seedling fresh weight and maximum seedling dry weight.

Keywords: Ber orchards, *In-vitro* conditions, Rhamnaceae, Rootstocks, Vigorous seedling

Ziziphus rotundifolia Lamk. (Wild ber), belongs to the family *Rhamnaceae*. It is one of the most important rootstocks for commercially grown ber orchards in India. It is native to an area that stretches from India to southwestern China and Malaya (Vavilov 1951). The area under ber cultivation in India is approximately 53,000 hectares with a production of 580,000 MT (2020-2021) and in Haryana, the area under ber cultivation is 4400 hectares with a production of 44,740 MT in 2020-21 (Anonymous 2020). *Zizyphus* is important underutilized fruit crop globally. Wild ber is frequently used as rootstock and hardy species against climate change. It is one of the hardest fruit trees and grows easily in a wide range of soils and climatic conditions. Currently, the area under cultivation of ber is continuously increasing but there is shortage of seedling availability. Improvement in the germination and production of vigorous seedlings is crucial for ber nursery growers. The ber rootstocks are prepared through seeds/ stones, as they are responsible for determining the quality of the orchard. Additionally, supplies water and nutrients to the plant and supports the plant, helping to regulate tree vigour, size and various other fruit characteristics. The ber rootstock produced from *Ziziphus rotundifolia* Lamk. is one of the

hardest rootstocks among ber species. Presently, rootstocks are prepared by sowing stones, but their germination is less uniform, poor and delayed due to the hard seed coat (endocarp). Seeds can be extracted from stones either mechanically or chemically but it might damage the embryo which results in irregular germination. The dormancy of seeds might be due to the hard seed coat which can be overcome to a greater extent by physical removal of seed coat or using pre-sowing treatments. The seed coat has an inhibitory role in gaseous exchange and seed germination.

Presowing treatments with bioinoculants and plant growth regulators (PGRs) play a significant role in seed germination and seedling growth of ber. Several fruit crops showed spectacular results from the use of PGRs in terms of germination, growth, yield, and quality. PGRs such as gibberellic acid (GA$_3$), 1-naphthalene acetic acid (NAA) and indole-3-butyric acid (IBA) enhance the germination, growth and survival ability of seedlings (Patel 2019). GA$_3$ is used to weaken seed coat dormancy so that the radicle of the seedling can break through the seed coat. It induces the synthesis of amylase and other hydrolytic enzymes during the early stages of seed germination and controls the mobilization of starch which acts as a respiratory substrate

leading to immediate enhancement in cell elongation. GA_3 also helps in enhance the availability of reserved mineral elements that promote the germination process. The seeds soaked in GA_3, NAA and IBA for 24 hours resulted in higher germination (Hakimi 2020). Scarification of ber seeds using 250 mg/L GA_3 for 24 hrs performed best in terms of germination and seedling growth under lab conditions (Sheoran et al 2019).

In recent years, bioinoculants have been used to suppress plant diseases (Heitefuss 2001) and nitrogen mobilization in soil (Saba et al 2012). They are less expensive alternatives to PGRs and boost productivity in short duration by enhancing the soil fertility and favouring phytopathogenic organism antagonism and biological control (Chirinos et al 2006). Bioinoculants stimulated seed germination compared to the control. The mechanism of action of plant growth-promoting rhizobacteria (PGPR) consists of enhancing the seed germination process and excreting phytohormones such as auxin and gibberellins. These factors improve seed germination and early seedling development. In addition to metabolic activities, bacteria excrete organic acids which help in nutrient uptake at later stages of growth (Bakonyi et al 2013). Inoculation with *Azotobacter* resulted in the earliest germination (14 days), 50 percent germination (17 days) and maximum germination percentage (82%) over the control (Subhashlal 2017). The prime motive of this experiment was to investigate the effectiveness of bioinoculants and plant growth regulators (PGRs) in improving the germination rate and seedling growth of wild ber seeds under *in-vitro* conditions.

MATERIAL AND METHODS

Experimental site: The present study on the effect of bioinoculants and PGRs on the germination and seedling growth of wild ber seeds was carried out at the Laboratory of Department of Seed Science and Technology (Location: $29°9'14.838"$ N, $75°42'8.178"$E), CCS Haryana Agricultural University, Hisar during 2021-22.

Planting material: The ripened fruits of *Ziziphus rotundifolia* were collected from the fruit orchard of the university (Location: $29°9'17.859"$ N, $75°41'40.238$ E"). The fruits were dipped in water tank to soften the pulp for stone removal. After that the stones were dipped in a water tank for 2-3 days and then shade dried to extract seeds mechanically from stones. All methods performed in this study involving the use of *Ziziphus rotundifolia* ripened fruits were conducted in accordance with the relevant institutional, national, and international guidelines, regulations, and legislation

Seed treatment: The seeds were treated with PGRs at concentrations of 50 mg/L and 100 mg/L each. PGRs were first dissolved in 95% ethyl alcohol or sodium hydroxide (NaOH). Then, a solution of 500 ml of each PGR was prepared. The seeds were soaked in the prepared solution for 24 hrs and then shade dried. For bioinoculants treatment, the seeds were first dipped in jaggery solution. Thereafter, the samples were mixed thoroughly with different bioinoculants each of concentration 1×10^8 CFU in a beaker for 30 minutes and shade dried. All the treatments of bioinoculants and PGRs were applied separately.

Treatment details: Twelve treatments with three replications each were selected based on previous literature. 75 seeds per replication were sown for the experiment. In addition, the formulations of bioinoculants with specific concentrations (T2 to T5) were grown in the laboratory of microbiology, CCSHAU, Hisar, India- 125004. Formulation T6 was collected from the Indian Agricultural Research Institute, New Delhi. After treatment the seeds were dried in the shade and then sown in between paper method.

Parameters Determined

Seed viability: Twenty-five seeds per replication were soaked in 50 mL water for 16 hours at 25°C to activate dehydrogenase enzymes. Seeds were di-sectioned longitudinally with a sharp blade and stained in 0.01 percent tetrazolium solution for 5 hours at room temperature in petri dishes. The seeds were rinsed in running tap water and seed viability was observed with the naked eye/ convex lens as a change in colour (pink). The germination parameters were evaluated after 24 hrs.

Germination percentage (GP): The germination percentage of the seeds was observed by keeping the treated seeds in between moist paper and keeping them in an incubator at a temperature of 25±2°C with 80-85% relative humidity. Radicle appearance was observed with an interval of every 24 hrs regularly up to 21 days after sowing.

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

Mean germination time (MGT) (days): Mean germination time (MGT) (days) was calculated by counting the normal germinated seeds (growth was normal after germination). MGT was considered to be when most of the seeds germinated. The germination count was taken at 24-hour interval for regular 21 days after sowing and calculated by the following formulae:

$$MGT = \frac{\Sigma nd}{\Sigma n}$$

where,

n = number of seeds that germinated on day d, and

d = number of days counted from the beginning of the germination test.

Seedling length (cm): Ten randomly selected normal seedlings per replication were taken for seedling length. It was measured from the root tip to the shoot tip with the help of a meter rod. Average seedling length was expressed in cm.

Fresh weight per seedling (mg): Ten randomly selected normal fresh seedlings were weighed.

Dry weight per seedling (mg): Ten randomly selected normal seedlings were kept in a hot air oven drier at 60±2°C until a constant weight was achieved. Dried weight of seedling was determined.

Seedling vigor: Seedling vigour indices I and II were calculated (Abdul baki and Anderson 1973)

Vigor index-I = Standard germination (%) × Average seedling length (cm)

Vigor index-II = Standard germination (%) × Average seedling dry weight (mg)

Correlation coefficients: Among all possible character combinations at the phenotypic 'r (p)' level ware estimated (Al-Jibouri et al 1958).

$$\text{Phenotypic correlation } r_{xy}\,(P) = \frac{Covxy(P)}{\sqrt{vx(P)\,XVy(P)}}$$

where, $Cov_{xy}\,(P)$ = Phenotypic covariance between characters 'x' and 'y'

$V_x\,(P)$ = Phenotypic variance of character 'x'

$V_y\,(P)$ = Phenotypic variance of character 'y'

Path coefficient analysis: This was performed as per Wright (1921) and adopted by Dewey and Lu (1959). Standard path coefficients, also referred to as the standardized partial regression coefficients, were calculated. These values were obtained by solving the following set of 'p' simultaneous equations using INDOSTAT software. This method was used to determine the direct and indirect paths.

Principal component analysis: PCA was performed to analyze complex datasets and is based on either correlation or variance-covariance matrices. Standardizing variables can address scale effects, especially when variables are measured differently. Correlation matrices are often preferred for extracting principal components in modern analyses.

Statistical analysis: The were statistically analysed using SPSS 16.0C.

RESULTS AND DISCUSSION

Seed viability and germination percentage: The seed viability was significantly influenced. The maximum seed viability of ber was recorded in 100 mg/L GA₃ followed by phosphoteeka, *Azospirillum* J 11-12, integrated biofertilizer (NPK- 1:1:1), 50 mg/L GA₃ and 100 mg/L IBA, was 92%, which was higher than that of all other treatments. The germination percentage (GP) was significantly influenced by

different presowing treatments with PGRs and bioinoculants (Table 1). GP was significantly increased with different presowing treatments when compared to the control. GP ranged from 54.22 to among different treatments. The maximum GP of ber seeds was in 100 mg/L GA₃ for 24 hours (80.44%) which was statistically at par with 50 mg/L GA₃ and integrated biofertilizer (NPK- 1:1:1). The minimum germination percentage (54.22%) was in control, which was statistically at par with 50 mg/L IBA and *Azospirillum* J 11-12. The GP with GA₃ increased because it acts as a growth regulator for breaking seed dormancy (Koyuncu 2005). It plays an important role in the germination of seeds by leaching out retardants. GA₃ aids the aleurone layer of the seed during the synthesis of hydrolytic enzymes that stimulate the α-amylase enzyme that converts insoluble sugar into soluble sugar (Babu et al 2010). GA₃ stimulates the cell wall to release and transmit its calcium into the cytoplasm. It affects the enzyme synthesis that produces mRNA and thereby increases DNA replication and induces analysis of endospermic materials in the seed (Lahuti et al 2003). The possible mechanism of PGPR in the seed germination process is based on the fact that bacteria can excrete phytohormones such as auxin and gibberellic acid and thereby, improve seed germination and early seedling development. Joshi et al. (2015) also reported that the germination of acid lime seeds was significantly influenced by 200 mg/L GA₃. Similar findings were reported by Karimpour et al. (2013). Hence, GA₃ increased the rate of reactions responsible for seed germination.

Mean germination time: The minimum MGT (9.7 days) was in 100 mg/L GA₃, which was statistically at par with *Azospirillum* J 11-12, 50 mg/L GA₃, Azoteeka- HT 54, 50 mg/L NAA, integrated biofertilizer (NPK- 1:1:1) and phosphoteeka. However, maximum MGT of 11.1 days was in control, which was statistically at par with Azoteeka- Mac 27 (Table 1). Early seed germination with GA₃ treatment might be due to stimulation of the α-amylase enzyme that converts insoluble sugar into soluble sugar, which provides energy for early seed germination. Sheoran et al. (2019) also reported that MGT was significantly influenced by 250 mg/L GA₃ for 24 hrs. Bioinoculants also help in early germination because the bacteria excrete phytohormones such as auxin and gibberellins, which are helpful to reduce MGT.

Seedling length (cm): The results reveal that seedling length was significantly increased by all pre-sowing seed treatments in comparison to the control. The maximum seedling length was in integrated biofertilizer (NPK- 1:1:1) (20.33 cm), which was statistically at par with 100 mg/L GA₃ and 50 mg/L GA₃ whereas, minimum seedling length (8.7 cm) was in   control (Table 2). higher seedling length with

integrated biofertilizer may be due to sufficient availability of nitrogen, phosphorus, potassium and other essential nutrients. The optimum supply of plant nutrients in the right amount at right time *i.e.*, during the vegetative growth period induce vegetative growth which ultimately increases seedling length. The higher seedling length with GA$_3$ may be due to the overall growth of seedlings and enhanced rate of photosynthesis and translocation of photosynthates in seedlings. Govind (2021) also reported that gibberellic acid significantly increased seedling length in bael and Hakimi (2020) reported the same in avocado.

Fresh and dry weight per seedling (mg): The fresh and dry weight per seedling was significantly increased by all pre-sowing seed treatments in comparison to the control (Table 2). The maximum fresh weight per seedling was in integrated biofertilizer (NPK- 1:1:1) (159.8 mg) which was statistically at par with 100 mg/L GA$_3$, 50 mg/L GA$_3$, Azoteeka-HT 54, 100 mg/L NAA and 50 mg/L NAA whereas, minimum fresh weight per seedling (123.3 mg) was in control. Dry weight per seedling at 21 DAS was maximum with in

integrated biofertilizer (NPK- 1:1:1) (35.06 mg), which was statistically at par with 100 mg/L GA$_3$ and 50 mg/L GA$_3$. The lowest dry weight per seedling (25.51 mg) was recorded for the control, which was statistically at par with the *Azospirillum* J 11-12, 50 mg/L IBA, 100 mg/L IBA, Azoteeka- Mac 27. The reason for higher fresh and dry weight per seedling with integrated biofertilizer may be due to sufficient availability of nitrogen, phosphorus, potassium and other essential nutrients. The optimum supply of plants nutrients in the right amount at the right time *i.e.*, during the vegetative growth period induce vegetative growth which ultimately increased seedling length and dry weight per seedling. The higher fresh and dry weight per seedling with GA$_3$ may be due to the overall growth of seedlings and enhanced rate of photosynthesis and translocation of photosynthates in seedlings. Kumar et al. (2020) also reported that fresh and dry weight of roots and shoots increased significantly by help of gibberellic acid in ber and Gupta et al (2018) reported the same in guava using biofertilizers.

Vigour indices: The vigor indices I and II were significantly

Table 1. Effect of bioinoculants and plant growth regulators on seed growth parameters of *Ziziphus rotundifolia*

Treatments	Seed viability (%)	Germination (%) 21 DAS	Mean germination time (days)	Seedling length (cm) 21 DAS	Fresh weight per seedling (mg) 21 DAS	Dry weight per seedling (mg) 21 DAS
Control (Untreated)	80	54.22	11.1	8.7	123.3	25.51
Azoteeka (*Azotobacter chroococcum*, Mac 27)	80	61.78	11	16.57	143.4	27.39
Azoteeka (*A. Chroococcum*, HT 54)	84	76	9.9	17.23	156.7	31.47
Phosphoteeka (*Pseudomonas*, P 36)	92	67.56	10.1	16.83	148.8	28.29
Azospirillum (J 11-12)	92	57.33	9.8	12.43	129.5	26.31
Integrated biofertilizer (NPK-1:1:1)	92	77.78	10.1	20.33	159.8	35.06
50 mg/L GA$_3$	92	79.56	9.8	19.9	158.1	33.59
100 mg/L GA$_3$	92	80.44	9.7	20.3	158.2	34.33
50 mg/L NAA	80	71.56	10	16.83	154.7	29.73
100 mg/L NAA	80	74.22	10.1	17.43	156.3	31
50 mg/L IBA	80	56.44	10.2	14.23	139.1	26.47
100 mg/L IBA	92	62.22	10.3	15.73	140.2	27.27
CD (p=0.05)	6.8	3.64	0.4	1.81	7.6	2.55

Table 2. Path coefficient analysis showing direct (Diagonal and bold) and indirect effects on component traits on dry weight per seedling

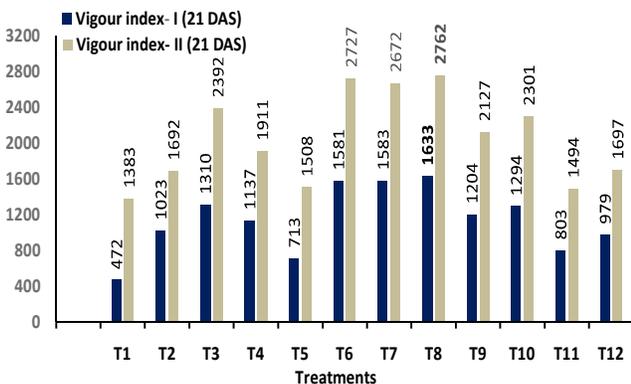| Variable	Seed viability	Germination percentage	MGT	Seedling length	Fresh weight per seedling	Dry weight per seedling
Seed viability	0.066	0.253	-0.029	0.081	-0.029	0.343
Germination percentage	0.019	0.881	-0.033	0.199	-0.169	0.898
MGT	-0.033	-0.492	0.058	-0.118	0.095	-0.489
Seedling length	0.024	0.772	-0.030	0.228	-0.173	0.820
Fresh weight per seedling	0.010	0.779	-0.029	0.206	-0.191	0.774

Residual effect= 0.4195

increased in presowing seed treatments as compared to the control (Fig. 1). The maximum vigour index I (1633) was d in 100 mg/L GA$_3$, which was statistically at par with 50 mg/L GA$_3$ and integrated biofertilizer (NPK- 1:1:1). However, the lowest vigour index I (472) was in control. The maximum value (2762) of vigour index- II was in 100 mg/L GA$_3$, which was statistically at par with integrated biofertilizer (NPK- 1:1:1) and 50 mg/L GA$_3$. However, the lowest vigour index- II (1383) was reported for the control, which were significantly at par with the 50 mg/L IBA and *Azospirillum* J 11-12. In the current study, GA$_3$ increased seedling length indicated in vigour index I. The vigour index II is based on the rate of dry matter accumulation and both indicates the availability of reserve food material and the termination of seed dormancy. The greater vigour index- II indicates more vigorous seed. The seedling length decreases as the spacing decrease, while the dry matter accumulation increases as the spacing increases. Both indices were tested in the laboratory and showed that the ber seed treated with 100 mg/L GA$_3$ had longer seedling length and greater dry matter accumulation. Ashish (2021) reported that vigour- I and vigour- II were found significantly better by help of gibberellic acid in papaya and also, Yadav (2021) reported the same in jatti khatti.

Correlation: The dry weight per seedling was the dependent variable among all the traits. The dry weight per seedling was positively and significantly correlated with seed viability (0.343), GP (0.898), seedling length (0.820) and fresh weight per seedling (0.774) whereas, negatively and significantly correlated with MGT (0.489) (Fig. 2).
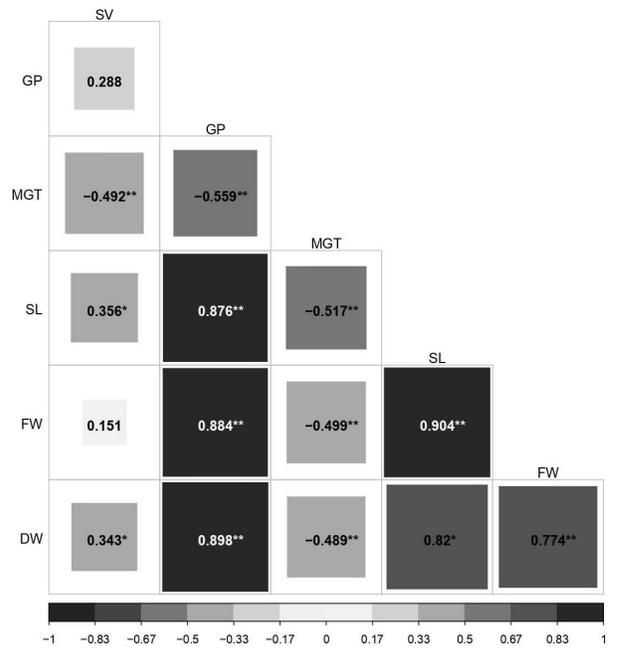
Path coefficient analysis: Using dry weight per seedling as a dependent variable and the rest of the traits as independent variables, the path coefficient analysis was used to evaluate the positive and negative, direct and indirect effects of different traits on dry weight (Table 3). The examination of

path coefficient analysis indicated that maximum direct positive on dry weight per seedling was imposed by GP (0.881) followed by seedling length, seed viability and MGT whereas, the maximum indirect positive effect was exhibited by fresh weight per seedling through GP (0.779) followed by seedling length through GP, seed viability through GP and fresh weight per seedling through seedling length. The residual effect at phenotypic level was 0.4195 which means there are some other traits or factors that affect dry weight per seedling.

Principal component analysis (PCA): Principal component analysis (PCA) condenses multiple variables into a few independent components, revealing their relative importance. In this study, PCA was conducted using the Sneath and Sokal method (1973), considering components with eigenvalues >1 (Kaiser 1958). Eigenvalues determined the number of factors retained, with the total variables equating to the sum of eigenvalues. The first two principal

*Significant at 5% level; **Significant at 1% level; SV, Seed viability; GP, Germination percentage; MGT, Mean germination time; SL, Seedling length; FW, Fresh weight of seedling; DW, Dry weight of seedling

Fig. 2. Phenotypic coefficients of correlation among different traits

Fig. 1. Effect of bioinoculants and plant growth regulators on Vigour index- I and Vigour index- II of *Ziziphus rotundifolia* seeds when utilizing the in between paper method
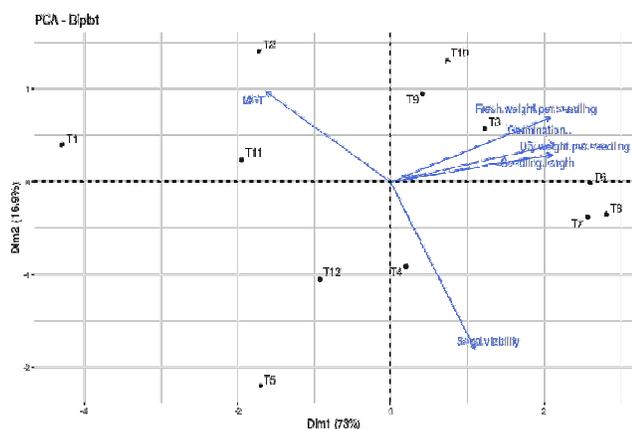
Table 3. Total variance explained by different principal components in treatments of wild ber

Principal component	Eigen value	Percentage of variance	Cumulative percentage of variance
PC1	4.38	72.993	72.993
PC2	1.014	16.896	89.889

Fig. 3. Principal component loading plot of PC-1 and PC-2

components (PC 1 and PC 2) had eigen value greater than one and they cumulatively explained 89.889% of the total variation present in original data set (Table 3). The first and second principal components explained 72.993 and 16.896 percent of the total variability, respectively.

The first principal factor showed high positive loading for germination percentage (0.461), dry weight per seedling (0.453), seedling length (0.451) and fresh weight per seedling (0.447). Principal factor two enabled high positive loading for seed viability (0.803). The PCA of the treatments is described in terms of spatial distance (Fig. 3). The biplot of genotypes based on PC-1 and PC-2 depicted 89.89% of total variation. The vector of traits, viz. dry weight per seedling, fresh weight per seedling and seed viability showed longer lengths, indicating positive contribution to both components.

The treatments of bioinoculants and PGRs have been distributed on the basis of their relative performance with respect to principal factor one and two. Principal factor one showed high loading for germination percentage, dry weight per seedling, seedling length and fresh weight per seedling. Therefore, treatments (T1, T2, T3, T6, T9, T10, T11) lying on the positive side of PF-1 show high variability for these particular traits. Principal factor two showed high loading for seed viability. The treatments (T3, T4, T6, T7, T8, T9, T10) lying on the positive side of PF-2 show high variability for these particular traits. In conclusion for both PC, treatments (T3, T6, T9, T10) lying on positive side of both PC shows high variability for germination percentage, seedling length, fresh weight per seedling and dry weight per seedling.

CONCLUSION

Different presowing treatments had a significant effect on improving seed germination and seedling growth of species *Ziziphus rotundifolia* compared to the control. The experiment showed that treating wild ber seeds with 100 mg/L gibberellic acid (GA$_3$) for 24 hours significantly improved seed viability, germination rate and vigour indices. Additionally, applying integrated biofertilizer (NPK- 1:1:1) for 30 minutes resulted in enhanced seedling growth in terms of length, fresh weight and dry weight. These findings underscore the efficacy of GA$_3$ and integrated biofertilizer in enhancing both seed germination and seedling growth, providing valuable insights for optimizing wild ber cultivation practices in controlled environments.

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Enhancing Apricot Growth and Leaf Nutrient Content Through Antioxidant and Bio-Regulator Applications

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Abstract: Antioxidants and plant bio-regulators were applied at critical developmental stages, specifically the pink bud and pit hardening stages. The results of the study revealed a significant augmentation in plant growth, along with notable increases in leaf macro- and micronutrient content, attributable to the application of these substances. The gibberellic acid at 50 ppm exhibited the most pronounced effects, with elevated levels observed in plant height, trunk girth, annual shoot growth, leaf area, and the concentrations of nitrogen, potassium, iron, copper, zinc, and manganese within the leaves. Conversely, ascorbic acid at 2000 ppm application demonstrated notable increases in total leaf chlorophyll content, as well as phosphorus, calcium, and magnesium concentrations within the leaf tissue. These findings elucidate the diverse impacts of exogenous substances on apricot physiology, emphasizing their role in fortifying plant vitality and enhancing leaf mineral status. The study contributes to understanding plant physiological dynamics and offers practical insights for optimizing agronomic practices to improve vegetative status as well as the mineral uptake efficiency of apricot across varied agro-ecological contexts.

Keywords: Apricot, Antioxidants, Plant bio-regulators, Leaf mineral content, Leaf chlorophyll

Apricot (*Prunus armeniaca* L.), a prominent stone fruit crop within the Rosaceae family and Prunoidae subfamily, thrives in temperate regions worldwide, including the USA, Spain, France, Italy, Turkey, Morocco, Iran, Africa, Australia, and India. Numerous studies have shown that antioxidants can improve photosynthetic efficiency and enhance nutrient uptake in plant by modulating hormonal signalling pathways involved in plant growth and development. Antioxidants are known to have a beneficial role in absorbing the free radicals (hydrogen peroxide, singlet oxygen, hydroxyl radicals, and ozone etc.) produced during plant respiration and photosynthesis (Abd Elhamid et al 2014). In contemporary agricultural practices, there is extensive utilization of naturally occurring and benign substances, notably antioxidants like ascorbic acid and citric acid, aimed at augmenting crop growth and productivity, with the ultimate goal of mitigating health risks. Ascorbic acid is a small and water soluble antioxidants that increases plant growth and photosynthesis attributes in stressful as well as non-stressful environments. It additionally serves a multitude of functions in plant growth (Hajivar et al 2020). Application of exogenous citric acid (CA) has been shown to enhance growth and yield in crop plants under varied conditions by enhancing physiological responses like increased photosynthetic rates, diminished reactive oxygen species levels, and improved osmoregulation, contributing to superior plant performance (Tahjib-Ul-Arif et al 2021).

In addition to these antioxidants, extrinsic application of plant bio-regulators has an advantageous impact on fruit crops' vegetative growth and leaf mineral content. Applying GA_3 to the leaves has been demonstrated to improve the mineral contents (N, K, Zn, Mn, and Fe) in the leaves, as well as promote vegetative characteristics including leaf size and chlorophyll content (Zhang et al 2016). PGR benzyladenine (BA), an artificially produced cytokinin molecule that exhibits diverse biological functions in the growth and development of plants, akin to naturally existing cytokinins. Cytokinins are endogenous plant hormones that govern plant growth, encompassing cellular division and leaf senescence (Sardoei et al 2014). The current study aimed to examine the use of naturally occurring and benign compounds, such as ascorbic acid and citric acid, as well as plant growth regulators (PGRs), in agriculture in order to boost crop growth and leaf mineral content.

MATERIAL AND METHODS

Location and climate: The present study was conducted at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, situated in Nauni, Solan (H.P.), India. The experimental site is located at an elevation of 1250 m above mean sea level, namely at 30º 51'N latitude and 76º 11'E longitude. The region in question is situated in the sub-temperate, sub-humid mid-hills agro-climatic zone II of Himachal Pradesh. This zone is distinguished by temperate

summers in May-June and cold winters in December-January. The geographical area under consideration exhibits an annual precipitation range of 110-120 cm, with the predominant occurrence taking place between the months of July to September.

Planting material and experimental details: The research was conducted on nine-year-old apricot cultivar New Castle, grafted onto seedling rootstocks. Twenty-seven plants exhibiting uniform vigour and size were selected and planted at a spacing of 5 × 5 m were subjected to various treatments (Table 1). These treatments were meticulously administered at the pink bud stage in February and reiterated at the pit hardening stage in April, over the span of 2019 and 2020. Crop harvesting was conducted during the final week of May.

In order to formulate stock solutions in advance within the laboratory, the preparation process entailed the meticulous weighing. On the day of application, dilutions were conducted directly within the experimental orchard. Bio-regulator (GA_3) was first dissolved in a tiny amount of 80 % pure alcohol while being constantly stirred, and then the volume was adjusted to one litre using distilled water. In a similar manner, the compound benzyladenine was initially dissolved in a limited amount of 0.1N sodium hydroxide (NaOH) while stirring continuously. Subsequently, the volume was adjusted to one litre by adding distilled water. The antioxidants were dissolved in distilled water. The final volume of the solution was adjusted to one litre for the stock solution. Subsequent dilutions were prepared according to the experimental specifications. The application of plant bio-regulators and antioxidants was carried out with great attention to detail in the morning hours. This was achieved by utilising a knapsack sprayer equipped with micro fine nozzles, which greatly enhanced the precision of the mist spray. The experiment was conducted in randomized block design with three replications.

Methodologies: Plant height measurements were conducted utilizing a graduated flag staff, wherein the distance from the base to the apex of each plant was recorded twice: initially before the onset of growth in January, and subsequently upon growth cessation in December. The increment in plant height was computed and presented as a percentage. Trunk girth was assessed at a standardized height of 15 cm above ground level, initially before the commencement of the experiment and subsequently upon cessation of growth. Measurements were recorded in centimetres (cms) and expressed as a percentage increase in trunk girth.

For annual shoot extension ten shoots from the current season's growth were randomly selected from different locations around the periphery of each plant. Following the cessation of growth, the length of these shoots was measured. To record leaf area, a total of 25 fully expanded and mature leaves were randomly sampled from various locations around the perimeter of each plant during June. Leaf area measurements were conducted utilizing a Leaf Area Meter (LI-COR Model 3100). The average leaf area was computed by dividing the cumulative leaf area measurements by the total number of leaves sampled, and the results were expressed in square centimetres (cm^2) per leaf.

For the determination of total chlorophyll content, ten fully expanded and mature leaves were harvested during the initial week of August in the morning hours. The leaves were promptly placed in an icebox to maintain their chlorophyll integrity and transported to the laboratory for analysis, ensuring preservation through refrigeration below 0°C. Upon arrival at the laboratory, the leaves from each sample underwent thorough washing and fine chopping. Subsequently, 10 mg of the finely chopped material was

Table 1. Effect of foliar application of antioxidants and plant bio-regulators on increase in growth and chlorophyll content of apricot cv. New Castle

Treatment	Per cent increase in plant height (%)	Per cent increase in plant girth (%)	Annual shoot extension (cm)	Leaf area (cm^2)	Leaf chlorophyll content (mg/100g fresh weight)
T1-Ascorbic acid (1000 ppm)	15.89[b]	4.41[cd]	101.29[abc]	42.25[b]	2.18[abc]
T2-Ascorbic acid (2000 ppm)	18.38[ab]	5.09[bc]	103.62[ab]	44.94[a]	2.57[a]
73-Citric acid (1000 ppm)	14.87[bc]	4.7[bcd]	94.05[de]	43.58[ab]	1.98[bc]
T4-Citric acid (2000 ppm)	17.22[b]	5.34[b]	97.35[cde]	42.79[b]	2.48[a]
T5-Benzyladenine (50 ppm)	15.09[bc]	3.95[de]	92.78[e]	41.58[b]	1.88[c]
T6-Benzyladenine (100 ppm)	16.15[b]	4.64[bcd]	99.55[bcd]	42.44[b]	2.16[abc]
T7-Gibberellic acid (25 ppm)	16.95[b]	6.87[a]	98.49[bcde]	41.95[b]	1.93[bc]
T8-Gibberellic acid (50 ppm)	20.98[a]	7.46[a]	105.79[a]	45.39[a]	2.34[ab]
T9-Control (Water spray)	11.49[c]	3.23[e]	79.81[f]	38.89[c]	1.41[d]

Figures with same letter in column do not differ significantly

transferred into vials containing 7 ml of dimethyl sulphoxide (DMSO). These vials were then subjected to incubation at a controlled temperature of 65°C for duration of thirty minutes. Following incubation, the resulting extract was transferred into graduated test tubes, and the final volume was adjusted to 10 ml with dimethyl sulphoxide (DMSO), adhering to the methodology outlined by Hiscox and Israelstam (1979). The optical density (OD) of the resultant extract was measured using a Spectronic-20D spectrophotometer at wavelengths of 645 nm and 663 nm, relative to a dimethyl sulphoxide (DMSO) blank to estimate the total chlorophyll content. The results obtained were then expressed as mg of chlorophyll per gram of fresh weight.

For the estimation of leaf mineral content, leaf samples were collected from the midsection of the current season's growth surrounding the tree perimeter, in accordance with the guidelines provided by Kenworthy (1964), during the final week of June to the middle of July. Cleaning, drying, grinding, and storage of the samples were conducted following the procedure outlined by Chapman (1964). The digestion of one-gram leaf samples for the estimation of nitrogen was carried out in concentrated sulphuric acid by adding the digestion mixture (potassium sulphate 480 parts, copper sulphate 20 parts, mercuric oxide 3 parts and selenium powder 1 part) as suggested by Jackson (1967). Total nitrogen content was subsequently estimated using the micro-Kjeldahl method (Jackson 1973). For the estimation of phosphorus, potassium, calcium, magnesium, iron, copper, zinc, and manganese, leaf samples were digested using a diacid mixture containing nitric acid and perchloric acid in a ratio of 4:1 (Jackson 1967). Phosphorus content was determined using the vanadate-molybdate phosphoric yellow color method (Jackson 1973). Potassium content was determined using a flame photometer. Total calcium, magnesium, iron, manganese, zinc, and copper were determined using a Perkin-Elmer Atomic Absorption Spectrophotometer model 400. Macro and micro-nutrient levels were expressed on a dry weight basis as percentage and parts per million (ppm), respectively.

All parameters investigated were recorded over the course of two years (2019-2020) and subjected to statistical analysis. Pooled treatment means were compared in OPSTAT utilizing the Duncan Multiple Range Test (DMRT) at a significance level of 5% (Duncan 1955).

RESULTS AND DISCUSSION

Tree growth: The vegetative traits of apricot underwent significant improvement due to the external application of various antioxidants and plant bio-regulators (Table 1). Gibberellic acid 50 ppm, ascorbic acid 2000 ppm, citric acid 2000 ppm, benzyladenine 100 ppm, and gibberellic acid 25 ppm predominantly led to notable enhancements in plant height during both years and in the aggregated data. The gibberellic acid 25 and 50 ppm, ascorbic acid 2000 ppm, citric acid 2000 ppm, and benzyladenine 100 ppm consistently yielded higher percentage increases in plant girth compared to alternative treatments The annual shoot extension showed higher percentage increases with gibberellic acid at 25 and 50 ppm, ascorbic acid at 2000 ppm and citric acid at 2000 ppm, when compared to other treatments. Among the treatments, gibberellic acid at 50 ppm consistently exhibited the highest percentage increase in plant height, plant girth and annual shoot extension throughout both years and in the aggregated data. The superiority of gibberellic acid in plant growth may be attributed to its role in controlling the cell elongation and cell division (Pires et al 2000) and direct effect on internodal elongation. Gibberellins also play a primary role in stimulating the auxin reaction, which helps in controlling the vegetative growth. The most typical property of gibberellins is promotion of stem growth. These findings are in conformity with Hazarika et al (2016) in papaya cv. Red Lady and Gholap et al (2000) in aonla.

The increase in plant vegetative parameters with the foliar application of antioxidants (ascorbic and citric acid) might be due to its auxin like actions, which ultimately cause cell division and growth (Ortiz-Espin et al 2017). Ascorbic acid is known for its capacity to enhance chlorophyll levels in leaves, hence augmenting photosynthetic efficiency and facilitating energy provision for diverse plant functions, including growth and development. In addition, also plays a role in cell division and enlargement and helps in organizing the growth processes and plant development eventually increasing the plant leaf area (Abd-El-Aziz et al 2006). These findings are in agreement with El-Badawy (2013) in Canino apricot. The application of gibberellic acid at higher concentrations (50 ppm) resulted in a notable increase in leaf area compared to the control and other treatments (Table 1). Gibberellic acid, known for its role in regulating plant growth and development, likely stimulated cell elongation and expansion, contributing to the observed augmentation in leaf area. The increase in leaf area due to gibberellic acid may be attributed to the role of gibberellins in both cell division and elongation (Batlang et al 2006). Gibberellic acid treatments also exerted notable effects on leaf chlorophyll content, particularly at higher concentrations (50 ppm), where significant increases were observed compared to the control and some other treatments. Gibberellic acid, known for its role in promoting cell elongation and expansion, may indirectly influence chlorophyll accumulation by enhancing leaf area and photosynthetic capacity. The present findings are also in

conformity with the results obtained by El-Naby et al (2019) in Canino apricot and Al-Rawi (2016) in peach cv. Peento. The observed increase in leaf area following the application of ascorbic acid, particularly at higher concentrations (2000 ppm), underscores its potential role as a stimulant for promoting leaf expansion and canopy development. This enhancement in leaf area can be attributed to the physiological effects of ascorbic acid, including its involvement in cell division, expansion, and maintenance of cellular integrity, thereby facilitating the proliferation of leaf tissue. Ascorbic acid treatments, particularly at higher concentrations (2000 ppm), elicited a significant increase in leaf chlorophyll content compared to other treatments and the control group. The superiority of ascorbic acid treatment in enhancement of chlorophyll content may be attributed to its role as an antioxidant Ascorbic acid acts as a cofactor for enzymes involved in the mechanisms of photosynthesis and hormone synthesis in plants. Ascorbic acid mitigates oxidative stress-induced senescence in wheat leaves by increasing the activities of catalase and ascorbate peroxidase, and reducing chlorophyll degradation.

Conversely, treatments involving citric acid and benzyladenine exhibited more varied effects on leaf chlorophyll content, with some treatments demonstrating either increases or decreases compared to the control. These contrasting responses may reflect the complex interplay between exogenously applied compounds and endogenous regulatory mechanisms governing chlorophyll metabolism, including its synthesis, degradation, and turnover rates. The augmentation in leaf chlorophyll due to exogenous application of antioxidants and PGR's may also be due to increased plant efficiency in absorbing elements from soil including Mg and Fe (Table 2, 3) leading to increasing their concentration in the leaves as are necessary and important for the formation of chlorophyll molecule (Fayed 2010). Similar findings pertaining to ascorbic acid application have been reported by El-Badawy (2013) in Canino apricot trees, Metep and Hasan (2020) in apricot cv. Zaghenia and Abdel-Salam (2016) in grape cv. Ruby. The control group, subjected to water spray, exhibited relatively

Table 2. Effect of foliar application of antioxidants and plant bio-regulators on NPK, calcium and magnesium content in leaf of apricot cv. New Castle

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
T1	2.36[e]	0.19[de]	2.42[d]	2.64[ab]	0.7[bc]
T2	2.75[a]	0.27[a]	2.72[ab]	2.69[a]	0.74[a]
T 3	2.41[de]	0.21[cd]	2.28[e]	2.46[c]	0.64[e]
T4	2.59[bc]	0.24[b]	2.46[d]	2.52[c]	0.66[de]
T5	2.35[e]	0.21[cd]	2.59[c]	2.53[bc]	0.63[e]
T6	2.49[cd]	0.23[bc]	2.63[bc]	2.51[c]	0.69[bcd]
T7	2.5[cd]	0.24[b]	2.64[bc]	2.49[c]	0.68[cd]
T8	2.67[ab]	0.27[a]	2.78[a]	2.56[bc]	0.72[ab]
T9	2.13[f]	0.17[e]	2.16[f]	2.22[d]	0.58[f]

For treatment details see Table 1
Figures with same letter in column do not differ significantly

Table 3. Effect of foliar application of antioxidants and plant bio-regulators on mineral content in leaf of apricot cv. New Castle

Treatments	Iron (ppm)	Copper (ppm)	Manganese (ppm)	Zinc (ppm)
T1	157.16[cd]	6.85[c]	47.97[c]	22.53[d]
T2	158.6[bc]	7.37[b]	48.55[c]	23.53[c]
T 3	155.54[cd]	7.06[bc]	48.78[c]	21.21[e]
T4	156.06[cd]	7.04[bc]	49.89[c]	22.24[d]
T5	157.67[cd]	8.11[a]	53.97[b]	24.2[bc]
T6	160.46[abc]	8.25[a]	55.37[ab]	24.55[b]
T7	163.46[ab]	8.21[a]	56.25[ab]	26.23[a]
T8	165.77[a]	8.47[a]	57.42[a]	26.55[a]
T9	152.24[d]	5.91[d]	44.76[d]	20.92[e]

Figures with same letter in column do not differ significantly
For treatment details see Table1

lower increase in plant height, girth, annual shoot extension, leaf area, and chlorophyll content values compared to the treated groups, underscoring the importance of applied treatments in modulating plant vegetative growth, chlorophyll metabolism and overall photosynthetic efficiency.

Mineral content in leaf: The leaf nitrogen content exhibited variation among the various treatments, with values ranging from 2.13 to 2.75% (Table 2). The nitrogen content was highest in 2000 ppm ascorbic acid and 50 ppm gibberellic acid, whereas control exhibited the lowest nitrogen concentration. There was variability in the leaf phosphorus percentage among the different treatments, with recorded values ranging from 0.17 to 0.27%. The leaf phosphorus content was maximum in 2000 ppm ascorbic acid and 50 ppm gibberellic acid . The amount of potassium exhibited variation among the different treatments, with recorded values varying between 2.16% to 2.78%. Application of 50 ppm gibberellic acid exhibited the highest concentration of leaf potassium whereas control demonstrated the lowest concentration of potassium. Al-Rawi et al (2016) observed significantly higher leaf nitrogen and potassium content with foliar application of GA_3 in peach cv. Peento. Soest (2012) reported that spray of gibberellic acid increased leaf P content in apple cultivar Anna. El-Badawy (2013) also mentioned that foliar application of ascorbic and citric acid gave significantly higher leaf N, P, and K content in "Canino" apricot.

Examination of calcium content in leaf indicated that treatments involving ascorbic acid (1000 ppm and 2000 ppm) demonstrated notable increases in leaf calcium levels compared to other treatments (Table 2). This observation suggested a potential role for ascorbic acid in enhancing calcium uptake in plants. Abd-El-Rhman et al (2017), reported increased leaf Ca content with foliar sprays of ascorbic acid at 2000 ppm in pomegranate. There was notable variation in magnesium uptake across the different treatments. Ascorbic acid 2000 ppm and gibberellic acid 50 ppm consistently showed higher magnesium percentages compared to other treatments suggesting a potential positive effect of these substances on magnesium uptake. The findings are in agreement with Daood and Shahin (2006) in apricot cv. Canino, and Soest (2012) in apple cultivar Anna.

Across the treatments and years, there were discernible variations in leaf iron status (Table 3). Treatments utilizing gibberellic acid at 25 and 50 ppm (T_8) consistently resulted in the highest iron percentages, indicating a potential positive influence of gibberellic acid on iron uptake by plants. Treatments with higher concentrations of gibberellic acid (T_7 and T_8) and benzyladenine (T_5 and T_6) consistently resulted in higher copper percentages. Treatments containing gibberellic acid (T_7 and T_8) and benzyladenine (T_5 and T_6) consistently resulted in higher leaf manganese and zinc compared to other treatments suggesting a potential positive influence of these substances on manganese and zinc uptake by plants. Soest (2012) also observed that spray of gibberellic acid increased leaf Zn and Fe content in apple cultivar Anna. Foliar sprays of 100 ppm GA_3 also increased leaf Fe content in peach cv. Peento (Al-Rawi 2016). Mahmoud et al (2015) reported that application of benzyladenine increased leaf Zn, Fe and Mn content over control in "Manzanillo" olives.

CONCLUSION

The notable influence of antioxidant and bio-regulator interventions on the growth of apricots and the nutritional profile of their leaves was evident. The effectiveness of different treatments, specifically gibberellic acid and high-concentration ascorbic acid, in strengthening plant vigour, increasing chlorophyll content, and improving leaf mineral uptake has been established through rigorous research and analysis. This provides a valuable insight for enhancing apricot cultivation techniques to enhance both crop output and quality.

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Evaluation of Radish Genotypes for Microgreens Production under Red and Laterite Zone of West Bengal

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Abstract: Radish is widely highlighted root vegetable due to its availability, nutrient content and potential health benefits. However, the adaptability of radish microgreens has not been explored much. Based on this an experiment was conducted to assess the performance of fourteen radish varieties (Palak Patta, White Cone, Indian Radish China Queen, NBR-Indian Queen, Bahar 32, Kashi Hans, Kashi Ardra, Pusa Chetki Long, Improved Radish Rajni, Sundar Lal Aush, Chinese Pink, Local 1, Local 2 and Local 3) at microgreen stage for different morphological and physicochemical traits. Variation was observed among the genotypes for plant height, hypocotyl length, root length, fresh weight, yield and different phytochemical parameters. Radish cv. NBR-Indian Queen produced maximum microgreen yield (661.38 g/m^2). Yield was positively correlated with plant height and hypocotyl length. Indian Radish China Queen recorded maximum amount of total phenol (145.67 mg GAE/100 g FW); whereas maximum ascorbic acid (202.587 mg/100 g FW) and beta carotene (19.98 µg of carotene/100 g FW) was in Pusa Chetki Long. The variation of morphological and nutrient composition among the different genotypes of radish offers the scope of selection of genotype. Radish cv. NBR-Indian Queen can be promoted to the growers for microgreen production.

Keywords: *Raphanus sativus*, Yield, Phenol, Beta carotene, Ascorbic acid

Microgreens are the new specialty food products which have acquired popularity and attention in recent years. These are young and tender cotyledonary leaves with a range of colour, texture and flavour. Now, they are widely recognised as source of health and longevity, making them a popular choice of culinary use. A wide array of crops can be grown as microgreen such as cabbage, broccoli, radish, amaranth, beet, *palak*, onion, etc. They are rich source of nutrients (K, Ca, Fe, Mg, Zn, Mo) as well as phytoactive compounds (α tocopherol, β carotene, ascorbic acid, phylloquinine, phenolic antioxidants, anthocyanins, glucosinolates, carotenoids, lutein, violaxanthin) which help to fight against various dreadful diseases such as cardiovascular, etc (Paradiso et al 2018, Xiao et al 2012). A small amount of microgreens contains 40 times higher concentration of elements (bioactive substances, vitamins and minerals) than their mature counterpart (Xiao et al 2012). Priti et al., 2021 noticed a wide variation in phytochemical composition, nutrient contents and antioxidant capacities in diverse genotypes of mungbean and lentil at microgreen stage. Variation in yield and nutrient composition provides a wide range of options for breeder to select suitable genotype to address specific need of growers and consumers.

Radish (*Raphanus sativus* L., Family Brassicaceae) is one of the important and popular root vegetable grown widely in tropical, subtropical and temperate regions. Radish roots and leaves are good source of several minerals and vitamins (Mallikarjunarao et al 2015, Singh et al 2017, Gamba et al 2021). On the other hand, radish microgreens are much enriched source of chlorophyll, carotenoids, anthocyanin, total phenolics, antioxidants (Zhang et al 2019). Because of crispy taste and presence of nutrients radish microgreens are quite popular. These are also regarded as immunostimulants due to antimicrobial action and anti-carcinogenic properties (Mlinerac et al 2023). India is the land of good source of radish genotypes. A number of varieties and hybrids have been developed by various public institutes and private companies. Many scientists have reported morphological and bio-chemical variation of root and shoot of radish. Tilahun et al(2023 mentioned the variation in yield, dry matter, chlorophylls, vitamin C, total phenolic, flavonoids and anthocyanin, K, Ca, Mg, and Na content in radish varieties in Korea. However, nutritional profiling of radish microgreens has yet not done properly in India. Keeping the above context, present experiment was conducted with the objective to study the performance of different radish genotypes for microgreens production with respect to vegetative characters and bio-chemical composition.

MATERIAL AND METHODS

The present investigation was carried out in a room specially designed for growing microgreens in Horticulture

Farm and Departmental Laboratory, Sriniketan during January 2023. The experimental room (6.0 m x 2.5 m) was fitted with netted windows and fans for proper ventilation. Shelves fitted with several compartments (97 cm x 34 cm each) were used to keep microgreen trays. Artificial light was provided by using LED lights of an average of 1900 ± lux capacity with a photoperiod of 12 hours in each compartment of shelf. Microgreens were raised in HDPE tray of 1.5 ft x 2 ft with a depth of 5 cm.

Fourteen different radish genotypes (Palak Patta, White Cone, Indian Radish China Queen, NBR-Indian Queen, Bahar 32, Kashi Hans, Kashi Ardra, Pusa Chetki Long, Improved Radish Rajni, Sundar Lal Aush, Chinese Pink, Local 1, Local 2 and Local 3) were taken for growing microgreens. The experiment was conducted following completely randomized design considering fourteen radish varieties as treatments with three replications. Before sowing, the trays were sterilized with the help of sodium hypochlorite (0.1%). Eight seeds per square inch were sown in mixed soilless substrate of cocopeat, perlite and vermiculite (3:1:1 ratio). The filled trays were placed in iron stacks for next seven days. Trays were watered as per the requirement by feel method to maintain optimum moisture level in the substrate. Radish microgreens were harvested at 1 cm above the substrate on seventh day after sowing and different morphological and physico-chemical parameters were observed.

The plant height, hypocotyl length, root length and leaf area were recorded. Total yield was calculated by harvesting all the microgreens and calculated per square metre. Fresh weight was computed by weighing ten healthy microgreens. Moisture content was estimated using formula after drying the fresh microgreens at 105°C for 3-4 hours and then taking the weight. Dry matter (%) was calculated and expressed as percentage of fresh weight. Total chlorophyll was assessed using Dimethyl sulfoxide (DMSO; Merck Life Science Private Limited, India) adopting the method of Hiscox and Israelstam (1979). Total phenol content was determined spectrophotometrically by using Folin-Ciocalteu reagent (Sisco Research Laboratories Pvt. Ltd., India) as described by Singleton et al (1999). Ascorbic acid content was estimated by titration method using meta phosphoric acid (Loba Chemi Pvt. Ltd., India) following the standard biochemical method (AOAC 1990). Beta carotene was estimated spectrophotometrically using β carotene (Sisco Research Laboratories Pvt. Ltd., India) as standard (Davis 1976). The total variation among the genotypes for different characters was tested for significance with Duncan's Multiple Range Test (IBM SPSS Statistics V22.0 Software) was used.

RESULTS AND DISCUSSION

Vegetative parameters: There were statistically significant differences in plant height, hypocotyl length and root length (Table 1). However, no significant difference in leaf area. The mean plant height was 7.56 cm. Radish varieties NBR-Indian Queen, Improved Radish Rajni and Kashi Hans recorded maximum plant height, which were statistically at par with each other. NBR-Indian Queen and Kashi Hans recorded

Table 1. Vegetative parameters of different radish microgreens

Treatment details	Plant height (cm)	Hypocotyl length (cm)	Root length (cm)	Leaf area (cm^2)	Fresh weight of 10 microgreens (g)	Yield (g/ m^2)
Palak Patta	6.98^{fg}	5.80^{j}	3.63^{efgh}	1.28	1.42^{a}	576.11^{b}
White Cone	7.87^{cd}	6.57^{efg}	3.43^{gh}	1.20	1.00^{e}	419.55^{g}
Indian Radish China Queen	7.40^{def}	6.50^{fgh}	3.70^{efg}	1.17	1.17^{cd}	387.62^{h}
NBR-Indian Queen	8.77^{a}	7.87^{a}	4.60^{b}	1.31	1.41^{a}	661.38^{a}
Bahar 32	8.07^{bc}	7.16^{cd}	3.87^{de}	1.18	1.22^{bcd}	590.10^{b}
Kashi Hans	8.43^{ab}	7.67^{ab}	3.43^{gh}	1.29	1.02^{e}	468.47^{f}
Kashi Ardra	7.80^{cd}	6.93^{cdef}	3.39^{h}	1.20	1.32^{ab}	482.58^{f}
Pusa Chetki Long	7.42^{def}	7.02^{cde}	4.11^{cd}	1.20	1.22^{bcd}	550.63^{cd}
Improved Radish Rajni	8.66^{a}	7.27^{bc}	5.05^{a}	1.14	1.29^{abc}	532.10^{de}
Sundari Lal Aush	6.20^{h}	5.17^{k}	3.53^{fgh}	1.20	1.38^{a}	565.82^{bc}
Local 1	6.57^{gh}	5.98^{ij}	3.81^{ef}	1.26	1.15^{cd}	517.62^{e}
Local 2	7.23^{ef}	6.40^{ghi}	4.27^{c}	1.33	0.99^{e}	588.79^{b}
Chinese Pink	6.97^{fg}	6.67^{defg}	3.60^{efgh}	1.29	1.02^{e}	462.49^{f}
Local 3	7.53^{de}	6.03^{hij}	3.67^{efgh}	1.27	1.15d	438.81^{g}

NS means statistically non-significant at 5% level of significance; Means with at least one letter common in a column are statistically at par using Duncan's Multiple Range Test

maximum hypocotyl length. The microgreen hypocotyl length varied from 5.17 cm to 7.87 cm. Similar range of hypocotyl length for radish in different cultivar and growing conditions was also reported by Li et al (2021) and Shibaeva et al (2022). The mean root length of radish microgreens was 3.86 cm; while maximum root length was registered in Improved Radish Rajni. Fresh weight of 10 microgreen plants varied from 1.00 g to 1.42 g. Maximum fresh weight was in Palak Patta, which was statistically similar to NBR-Indian Queen and Sundari Lal Aush. Tilahun et al (2023) observed significant difference among the five radish cultivars in fresh weight. The mean yield for radish microgreen was 517.29 g/m^2. The maximum yield (661.38 g /m^2) was achieved in NBR-Indian Queen. Greater plant height, more hypocotyl and root length and greater fresh weight of the seedlings might contribute towards more yield in the present experiment. Yield variation in radish microgreens due to genotypes was also reported by Tilahun et al (2023). Palmitessa et al. (2020) also confirmed the variation in microgreen yield in different *Brassica* species. Bulgaria et al (2021) recorded yield variation in basil varieties.

Physico-chemical parameters: Significant variation was noted for different physico-chemical parameters under the present study (Table 2). Moisture content of radish microgreens varied from 87.16 to 94.10%, while dry matter content was ranged from 5.90 to 12.84%. Maximum moisture content was in Kashi Ardra (94.10%), which was statistically at par with Sundari Lal Aush, Palak Patta and NBR- Indian Queen. Kowitcharoen et al (2021) observed moisture content

of 91.88, 93.19 and 93.50% in purple radish, radish and rat tail radish microgreens respectively. *Brassica* microgreens, especially radish have thicker stem and leaves as compared to others, which resulted higher biomass content. The maximum dry matter content was observed under genotype Pusa Chetki Long (12.84 %) which was statistically similar to genotype Local 3 (12.28 %) followed by White Cone and Chinese Pink. The mean dry matter was 9.31%. Similar dry matter content was reported by Amitrato et al (2023) in radish and Kyriacau et al (2020) in knolkhol microgreens. Improved Radish Rajni showed maximum total chlorophyll content (3.28 mg/g microgreen FW) which was statistically similar with Bahar 32. This indicates the elevated chlorophyll content in several radish genotypes. Higher chlorophyll content gave a good lustre and vibrant leaf colour which enhances the visibility of microgreens. The chlorophyll is also associated with antioxidant activity (Lanfer-Marquez et al 2005). The total phenol, ascorbic acid and beta carotene were varied for different genotypes. The mean values of total phenol, ascorbic acid and beta carotene were 97.28 mg GAE/100 g FW, 146.65 mg/100 g FW and 11.07 μg of carotene/100g FW respectively. The concentration of phenol varies distinctly from genotype to genotype with the range of 55.97 to 145.67 mg GAE/100 g fresh weight. Maximum phenol content was in Indian Radish China Queen. Tan et al (2020) observed the presence of phenolic compounds were associated with the taste and flavour of the crop. Microgreens from Brassicaceae family posses good amount of phenolic antioxidants (Paradiso et al 2018). Saleh et al. (2022) observed higher

Table 2. Physicochemical parameters of different radish microgreens

Treatment details	Moisture (%)	Dry matter (%)	Total chlorophyll (mg/g microgreen FW)	Total phenol (mg GAE/100 g FW)	Ascorbic acid (mg/100 g FW)	Beta carotene (μg of carotene/100g FW)
Palak Patta	93.61[ab]	6.39[e]	1.13[e]	90.37[e]	188.06[c]	5.85[fg]
White Cone	89.27[e]	10.73[b]	1.09[e]	55.97[g]	107.42[i]	3.52[g]
Indian Radish China Queen	92.6[c]	7.40[d]	1.18[de]	145.67[a]	81.04[l]	23.23[a]
NBR-Indian Queen	93.75[ab]	6.25[e]	1.52[cd]	133.19[b]	176.73[e]	7.93[ef]
Bahar 32	92.18[c]	7.82[d]	3.01[a]	91.23[e]	132.94[f]	13.36[bc]
Kashi Hans	92.34[c]	7.66[d]	0.60[f]	127.67[b]	118.48[h]	12.33[bcd]
Kashi Ardra	94.10[a]	5.90[e]	0.67[f]	91.57[e]	125.45[g]	9.55[def]
Pusa Chetki Long	87.16[f]	12.84[a]	1.14[e]	94.55[e]	202.587[a]	19.98[a]
Improved Radish Rajni	92.83[bc]	7.17[d]	3.28[a]	102.77[d]	178.49[e]	13.85[b]
Sundari Lal Aush	94.08[a]	5.92[e]	2.42[b]	96.45[de]	183.28[d]	9.52[def]
Local 1	91.21[d]	8.79[c]	1.45[cde]	76.74[f]	199.07[b]	8.49[ef]
Local 2	90.92[d]	9.08[c]	2.31[b]	116.51[c]	177.72[e]	9.13[def]
Chinese Pink	89.91[e]	10.09[b]	1.68[c]	58.48[g]	83.81[k]	9.97[cde]
Local 3	87.72[f]	12.28[a]	1.15[e]	80.74[f]	98.02[j]	8.24[ef]

Means with at least one letter common in a column are statistically at par using Duncan's Multiple Range Test (p=0.05).

phenolic content under various species of Brassicaceae family (Pak choi, Kale). The ascorbic acid content of radish microgreens has been ranged from 81.04 mg/100g FW (Indian Radish China Queen) to 202.58 mg/100 g FW (Pusa Chetki Long). Marchioni et al. (2021) also reported a wider variation in ascorbic acid content in different Brassica microgreens (broccoli, daikon, mustard, rocket salad and water cress). The beta carotene content was highest in Indian Radish China Queen (23.23 µg of carotene/100g FW), which was statistically at par with Pusa Chetki Long. Xiao et al (2012, 2019) reported variation in beta carotene content in different radish and other species of Brassicaceae family. Variation in beta carotene and ascorbic acid was also noted by Kamal et al (2020) in different species of *Brassica* such as different types of cabbages (cabbage green, cabbage red, cabbage savoy), mustard (mustard dijon, mustard red), kale (Kale Chinese, Kale red, Kale Tuscan), etc. Kowitcharoen et al (2021) found the variation in bioactive compounds in three different types of radish (purple radish, radish and rat tail radish). Variation in mineral composition of cabbage was reported by Podsedek et al (2023). Their study revealed that red cabbage microgreens had higher total chlorophyll, total carotenoid and total phenol as compared to the white cabbage. Yadav et al (2018) observed variation in total phenol and ascorbic acid in three types of *Amaranthus* microgreens.

Association of morpho-biochemical parameters: There was strong relation between plant height and hypocotyl length and positive correlation was observed among yield and hypocotyl length. Ampim et al (2021) also observed similar trend in Egyptian spinach and vegetable amaranth microgreens. Similarly, strong correlation was observed among yield and root length. Fresh weight of 10 seedlings was negatively correlated to hypocotyl length and leaf area. The hypocotyl length and yield was also negatively correlated with the dry matter. This was in agreement with the study of Toscano et al (2023). Yield was positively correlated with total chlorophyll, total phenol and ascorbic acid. The total phenol was positively correlated with ascorbic acid and ascorbic acid with beta carotene. Ghoora et al (2020) mentioned that phytochemical quality of microgreens is related to total phenol content and ascorbic acid content. However, present study showed that ascorbic acid and total chlorophyll were negatively associated with hypocotyl length. Jones-Baumgardt et al (2021) reported that some phytochemical properties such as ascorbate of *Brassica* microgreens had altered relation with the hypocotyl length.

The presence of variability among radish genotypes in morphological as well as biochemical characteristics have helped to select the desirable one (Kumar & Sharma 2011, Kurina et al 2021). Bokhan et al (2015) stated that the

Table 3. Estimation of correlation coefficients among vegetative attributes and physicochemical attributes of different radish microgreens

	Plant height (cm)	Hypocotyl length (cm)	Root length (cm)	Leaf area (cm²)	Fresh weight of 10 microgreens (g)	Yield (g/m²)	Moisture (%)	Dry matter (%)	Total Chlorophyll (mg/g microgreen FW)	Total Phenol (mg GAE/100 g FW)	Ascorbic acid (mg/100 g FW)	Beta carotene (µg of carotene/100g FW)
Plant height (cm)	1.0000											
Hypocotyl length (cm)	0.8928	1.0000										
Root length (cm)	0.4647	0.4143	1.0000									
Leaf area (cm²)	-0.1129	0.0053	-0.0820	1.0000								
Fresh weight of 10 microgreens (g)	0.0197	-0.0947	0.2510	-0.2458	1.0000							
Yield (g/m²)	0.0962	0.1468	0.5372	0.2790	0.5368	1.0000						
Moisture (%)	0.1071	0.0429	0.0648	-0.0909	0.5802	0.3416	1.0000					
Dry matter (%)	-0.1071	-0.0429	-0.0648	0.0909	-0.5802	-0.3416	-1.0000	1.0000				
Total Chlorophyll (mg/g microgreen FW)	0.0472	-0.0364	0.6081	-0.3163	0.1504	0.4562	0.1922	-0.1922	1.0000			
Total Phenol (mg GAE/100 g FW)	0.3610	0.3692	0.3367	0.0538	0.2232	0.2103	0.4527	-0.4527	-0.0057	1.0000		
Ascorbic acid (mg/100 g FW)	-0.1651	-0.1283	0.4917	0.0746	0.4864	0.7629	0.1725	-0.1725	0.3000	0.0888	1.0000	
Beta carotene (µg of carotene/100g FW)	0.0901	0.2484	0.1975	-0.4757	-0.0001	-0.1959	-0.0884	0.0884	0.0762	0.5303	-0.1010	1.0000

concentration of chemical composition differs according to species and varietal characteristics.

CONCLUSION

The intake of microgreens is associated with the profuse presence of beneficial elements which have to improve immune system of our body. The variation of nutrient composition among the different genotypes of radish offers the scope of selection of genotype. Among the studied radish genotypes, the production performance of NBR-Indian Queen was good with high yield potential. The genotype Pusa Chetki Long and Indian Radish China Queen showed good presence of ascorbic acid, total phenol and beta carotene, which are regarded as valuable antioxidant compounds. However, these two genotypes were average yield performer. Thus more radish accession should be screened to identify genotype(s) which produce more biomass as well as high bioactive compounds. Such genotypes can also be developed through transgressive breeding using the identified genotypes. It is suggested that the selection of radish genotypes for microgreen production need to be done based on the yield and nutritional composition, which will be economical for the growers and beneficial for the consumers. However, based on the present study radish cv. NBR-Indian Queen can be promoted to the growers for microgreen production.

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Effect of Different Fertilizer Levels, Biostimulant and Novel Organic Liquid Nutrient on Growth and Yield of Beet Root (*Beta vulgaris* L.)

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Abstract: Experiment was conducted during *rabi* season of 2020-21 and 2021-22 to study the influence of different fertilizer levels, biostimulant and novel organic liquid nutrient on growth and yield attributes parameters of beet root (*Beta vulgaris* L.). Present investigation comprising three factors *viz*., three levels of fertilizer *viz*., 40 % RDF , 60 % RDF and 80 % RDF, biostimulant *viz*., *Jeevamruta*, *Panchagavya*) and Bio NPK Consortium and three levels of novel organic liquid nutrient *viz*., 1.0 % , 1.5 % and 2.0 % . The maximum different growth and yield parameters *viz*., plant height at 30 DAS and harvest (cm), number of leaves per plant at 30 DAS and harvest, leaf area per plant (cm^2), leaf area index, root weight per plant (g), marketable root yield (kg plot^{-1}), marketable root yield (t ha^{-1}), total root yield (kg plot^{-1}), total root yield (t ha^{-1}) and minimum days taken for harvest were observed with application of 80 % RDF . application of *Panchagavya* @ 3 % (b$_2$) and application novel organic liquid nutrient @ 2.0 % (n$_3$) in both the years.

Keywords: Beet root, Biostimulant, Novel organic liquid, *Jeevamruta, Panchagavya* and Bio NPK Consortium

Beet root (*Beta vulgaris* L.), is one of the major root vegetable belongs to the family Amaranthaceae along with spinach, palak, swiss chard, parsley and celery. Beet root originated in Western Europe and North Africa where they were grown to feed both by humans and livestock. It produces green tops and swollen root used both as vegetable and salad. Vegetable often eaten without any processing are more vulnerable to contamination with chemical due to their residual toxicity as compared to cereals and pulses. Thus, organic production of vegetable is becoming more popular than other crops. Biostimulents are natural substances derived from plants and animals influence plants metabolic processes such as respiration, photosynthesis, nucleic acid synthesis and ion uptake (Khan et al 2009). NOVEL organic liquid nutrient is the byproduct of banana pseudo stem and contains good amount of essential macro and micro nutrients as well as growth boosters (Salunkhe 2010). Integrated nutrient management is an alternative for sustainable crop production rather than use of inorganic fertilizers only. The combined use of organic manures, biostimulant, novel organic liquid nutrient with a reduced dose of chemical fertilizers, not only pave the way for higher yield and quality produce, but also help to maintain the soil health and reduce pollution problems. The prevent study was conducted on influence of different fertilizer levels, biostimulant and novel organic liquid nutrient on growth and

yield attributes parameters of beet root (*Beta vulgaris* L.).

MATERIAL AND METHODS

Field experiment was conducted at Sardarkrushinagar Dantiwada Agricultural University, Jagudan, Mehsana during the years 2020-21 and 2021-22 on beet root. The soil of the experimental location was loamy sand with normal pH (7.91), low in available nitrogen (185.25 kg ha^{-1}), medium in available phosphorus (46.29 kg ha^{-1}) and high in available potassium (275.45 kg ha^{-1}). The experiment was laid out in randomized block design with factorial concept keeping three factor *viz*., different fertilizer levels, biostimulant and different concentration of novel organic liquid nutrient. The twenty-seven treatments were replicated thrice . Beet root was sown by. In this experiment beet root crimson glob cultivar was sown on 25 October in both the years by hand dibbling method / FYM @ 20 t/ha was applied in all the treatments at the time of land preparation. Half dose of N and full dose of P and K was given as per treatment as a basal dose. Remaining half dose of N was applied in two split as a top dressing at 30 and 45 DAS. *Jeevamruta* was applied in soil as per treatment through drenching @ 500 l/ha at the time of sowing and 30 DAS, *Panchgavya* was sprayed as per treatment @ 3 % at 20, 35 and 50 DAS, Bio NPK consortium was applied in soil as per treatment @ 1.5 l/ha at the time of sowing by mix with required quantity of FYM and Novel

organic liquid nutrient was sprayed as per treatment (1.0 %, 1.5 % and 2.0 %) at 20, 35 and 50 DAS.

RESULTS AND DISCUSSION

Growth parameters: The 80 % RDF recorded significantly higher plant height at 30 DAS and at harvest on number of leaves per plant at harvest, leaf area per plant and leaf area index Significantly minimum days for harvest were observed with application of 80 % RDF. The larger canopy and plant height under the application of higher dose of fertilizer might have increased interception, absorption and utilization of solar energy which in turn increased overall growth, photosynthesis and finally accumulation of dry matter per plant. The observed improvement in overall vegetative growth of the crop with the application of NPK in the present investigation were in conformity with those of Anuradha et al (2017) in cluster bean. The application of @ 3 % *Panchagavya* recorded significantly higher plant height at 30 DAS and at harvest, number of leaves per plant at harvest, leaf area per plant and leaf area index (Table 1, 2). Significantly minimum days for harvest was with application of @ 3 % *Panchagavya*. The increase in plant height might be due to application of nutrients through foliar spray of *Panchagavya* enhanced the growth rate of plant since it contains the favorable macro and micronutrients, growth hormones and bio-fertilizers in liquid formulation. Moreover, the presence of growth enzymes in *Panchagavya* might have favored rapid cell division and elongation. Similar findings were also reported by Jabeen et al (2018) in spinach beet and Jagadeesh (2018) in beet root. The application of novel organic liquid nutrient @ 2.0 % recorded significantly higher plant height at 30 DAS and at harvest, number of leaves per plant at harvest, leaf area per plant and leaf area index. Significantly minimum days for harvest were with the application of novel organic liquid nutrient @ 2.0 %. This might be due to nitrogen which present in novel organic liquid fertilizer is responsible for the formation, growth and development of the cells and accelerating the synthesis of chlorophylls which are associated with major photosynthesis process of plants, which enhances the formation of meristematic tissues as observed by Deore et al (2010) in chilli. Similar findings were observed by Champaneri (2020) in Indian bean. The different fertilizer levels, biostimulant and novel organic liquid nutrient application had non-significant influence on number of leaves per plants at 30 DAS. The interaction between different combination of treatments (f × n, b × n and f × b × n) exhibits non-significant effect on different growth parameters, except plant height at

Table 1. Effect of fertilizer levels, biostimulant and novel organic liquid nutrient on plant height at 30 DAS, plant height at harvest, number of leaves per plant at 30 DAS and number of leaves per plant at harvest

Treatment	Plant height at 30 DAS (cm)	Plant height at harvest (cm)	Number of leaves per plant at 30 DAS	Number of leaves per plant at harvest
Fertilizer levels (f)				
f_1	14.71	29.90	5.93	11.07
f_2	15.93	31.82	6.08	12.67
f_3	16.77	33.10	6.11	13.73
CD (p=0.05)	0.38	0.86	NS	0.30
Biostimulant (b)				
b_1	15.29	30.34	5.93	11.83
b_2	16.33	32.90	6.14	13.18
b_3	15.79	31.57	6.05	12.46
CD (p=0.05)	0.38	0.86	NS	0.30
Novel organic liquid nutrient (n)				
n_1	15.42	30.82	5.94	12.22
n_2	15.79	31.55	6.06	12.46
n_3	16.20	32.45	6.12	12.79
CD (p=0.05)	0.38	0.86	NS	0.30
Interaction effect				
f × b	0.65	1.50	NS	0.52
	6.25	7.16	7.77	6.25
CV (%)				

The interaction fxn, bxn and fxbxn was not significant

Table 2. Effect of fertilizer levels, biostimulant and novel organic liquid nutrient on days taken for harvest, leaf area per plant and leaf area index

Treatment	Days taken for harvest	Leaf area per plant (cm^2)	Leaf area index
Fertilizer levels (f)			
f_1	76.38	1260.05	2.80
f_2	71.66	1307.38	2.91
f_3	68.39	1341.17	2.98
CD (p=0.05)	2.06	36.18	0.08
Biostimulant (b)			
b_1	74.21	1270.01	2.82
b_2	70.07	1337.16	2.97
b_3	72.14	1301.43	2.89
CD (p=0.05)	2.06	36.18	0.08
Novel organic liquid nutrient (n)			
n_1	74.08	1271.04	2.82
n_2	71.89	1299.62	2.89
n_3	70.45	1337.94	2.97
CD (p=0.05)	2.06	36.18	0.08
Interaction effect			
CV (%)	7.49	7.28	7.28

The interaction fxb, fxn.bxn and fxbxn was not significant

Table 3. Effect of fertilizer levels, biostimulant and novel organic liquid nutrient on root length, root width, root weight per plant and marketable yield

Treatment	Root length (cm)	Root width (cm)	Root weight per plant (g)	Marketable root yield per plot (kg)
Fertilizer levels (f)				
f_1	6.78	6.65	132.60	3.64
f_2	7.33	6.82	157.64	4.31
f_3	7.69	6.86	173.78	4.79
CD (p=0.05)	0.15	NS	5.26	0.17
Biostimulant (b)				
b_1	7.04	6.66	144.20	3.96
b_2	7.49	6.88	165.27	4.54
b_3	7.27	6.79	154.55	4.23
CD (p=0.05)	0.15	NS	5.26	0.17
Novel organic liquid nutrient (n)				
n_1	7.12	6.71	148.83	4.08
n_2	7.26	6.75	154.52	4.24
n_3	7.42	6.87	160.68	4.42
CD (p=0.05)	0.15	NS	5.26	0.17
Interaction effect				
f × b	NS	NS	9.11	0.30
CV (%)	5.39	8.24	8.91	10.70

The interaction fxn, bxn and fxbxn was not significant

30 DAS and at harvest and number of leaves per plant at harvest where observed significant variation with treatment combination (f × b).

Yield parameters: The significantly higher root length, root weight per plant, marketable root yield per plot, total root yield per plot, marketable root yield per hectare and total root yield per hectare were recorded with 80 % RDF. The results of present investigation were in line with those of Raiger et al (2017) in cluster bean. The application of @ 3 % *Panchagavya* recorded significantly the higher root length, root weight per plant, marketable root yield per plot, total root yield per plot, marketable root yield per hectare and higher total root yield per hectare (Table 2). Milk in *Panchagavya* provides fat, carbohydrates, protein, amino acids and calcium and curd gives lactobacillus which act as catalyst in the decomposition of organic waste. Such finding is supported by Swain et al (2015) chilli. Amongst the yield parameters, significantly higher root length, root weight per plant, marketable root yield per plot, total root yield per plot, marketable root yield per hectare and total root yield per hectare were obtained with novel organic liquid nutrient @ 2.0 %. Kalariya et al (2018) also observed similar trend in okra. The root width and harvest index (%) was significantly

Table 4. Effect of fertilizer levels, biostimulant and novel organic liquid nutrient on total root yield per plot , marketable root yield per hectare , total root yield per hectare and harvest index

Treatment	Total root yield per plot (kg)	Marketable root yield per hectare (t)	Total root yield per hectare (t)	Harvest Index (%)
Fertilizer levels (f)				
f_1	4.26	25.26	29.61	53.95
f_2	5.03	29.92	34.92	52.08
f_3	5.57	33.24	38.66	50.62
CD (p=0.05)	0.21	1.20	1.43	NS
Biostimulant (b)				
b_1	4.62	27.47	32.09	53.27
b_2	5.29	31.55	36.74	51.33
b_3	4.96	29.40	34.41	52.05
CD (p=0.05)	0.21	1.20	1.43	NS
Novel organic liquid nutrient (n)				
n_1	4.77	28.32	33.12	51.99
n_2	4.93	29.41	34.25	52.22
n_3	5.16	30.68	35.83	52.44
CD (p=0.05)	0.21	1.20	1.43	NS
Interaction effect				
f × b	0.36	2.08	2.48	NS
CV (%)	10.91	10.70	10.91	13.86

The interaction fxn, bxn and fxbxn was not significant

not affected by different fertilizer levels, biostimulant and novel organic liquid nutrient application. The result showed that interaction between different combination of treatments (f × n, b × n and f × b × n) exhibits non-significant effect on different yield parameters, except root weight per plant, marketable root yield per plot, total root yield per plot, marketable root yield per hectare and total root yield per hectare. The significant effect with the treatment combination of (f × b) was observed.

CONCLUSION

The higher growth and yield can be obtained through combined application of 80 % recommended dose of fertilizer and foliar spray of *Panchagavya* 3 % at 20, 35 and 50 days after sowing of beet root during *rabi* season.

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Influence of Land Configuration and Weed Management Options on Soil Properties and Nutrient Uptake by Pigeonpea (*Cajanus cajan* L.)

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Abstract: Experiment was carried-out during *kharif* season of 2020 at research farm of Indian Agricultural Research Institute-New Delhi in three times replicated split- plot design with three land configurations (main-plot) while, six weed management options (sub-plot) to assess the effect of these land configuration and weed management options on soil fertility and nutrient uptake by pigeonpea. Results showed that Broad bed and furrow planting recorded higher N, P and K content (3.19, 0.36, 1.24% and 1.22, 0.22, 1.83% in seed and stalk, respectively) and thereby enhanced their uptake (9.4, 19.6, 9.9% and 10.1, 16.5 and 23.2% in seed and stalk, respectively) over flatbed plating apart from contributing higher organic carbon (OC), available N, P and K in the soil. Among weed management options, two-hand weeding (30 and 60 DAS) recorded enhanced N, P and K uptake by seed and stalk; the increase being 61.3, 76.9, 49.3 and 49.3, 162.0, 65.8%, respectively and maintain higher OC, available N, P and K in soil over weedy-check. However, weed-free condition (twice hand weeding) fetched higher protein content and protein yield. Overall, pigeonpea grown on broad bed and furrow with two hand weeding proved better with respect to OC, available soil nutrients (N, P and K) and their uptake, protein yield as well as in soil microbial properties.

Keywords: Land configuration, Weed management, Soil properties, Nutrient uptake, Pigeonpea

Pulses are staple food crops in several countries where they play a vital role in addressing the nation's food and nutritional security, and also assisting in tackling the environmental challenges. Pulses contribute ~ 9-10 per cent in total food production acting as critical and inexpensive source of proteins, vitamins, dietary fibre and minerals, etc. (Tewari et al 2019). Moreover, they also support the economy of the rainfed regions where they contribute to a more sustainable food system by increasing soil fertility (owing to their ability to fix atmospheric nitrogen and physical structure), providing green vegetables (pods/beans) and fodder for cattle, and fitting well into mixed/intercropping systems, crop rotation, and dry farming (Dass and Sudhishri 2010, Sharma et al 2019).

In India, pigeon pea [*Cajanus cajan* (L.) Millsp.] is the second utmost important pulse crop after chickpea. Globally, India ranks first in the pigeon pea production with 4.14 million tonnes from 4.71 million hectares and productivity of 877 kg/ha (Government of India 2021). More than 80% area under pulses production is under rainfed and traditional cultivation on marginal and sub-marginal lands, resulting in low productivity and high instability in pulse production (Dass and Sudhishri 2010, Ahlawat et al 2016). However, similar to other crops, the production of pigeon peas is often constrained by a number of biotic and abiotic elements, such as weed competition, moisture stress, nutrient deficiencies, and microbial parameters. Therefore, it is essential to exercise control over these aspects to increase pigeonpea productivity and sustainability (Garud et al 2018). Though pigeon pea is a deep-rooted crop, which is well known for drought tolerance under rainfed upland ecosystem, prolonged dry spells during early growth and flowering to pod formation stages severely affects crop growth and yield (Sangma 2020). Moreover, heavy weed infestation also elevates extreme moisture stress and nutrient deficiencies through increased crop weed competition. Due to severe weed competition; the yield of pigeon pea is reduced by 31.0-52.8% (Chaudhary and Dhakal 2023). Despite the yield loss, weeds infestation causes a decline in the inputs-use efficiency of fertilizers and water, ultimately increases the cost of cultivation (Kumar et al 2023). Thus, it is important to devise suitable management options to mitigate weeds problem, moisture and nutrient stress. Change in the current land configuration might be one of the best ways to conserve and enhance moisture availability to the crop plants throughout the growing season (Garud et al 2019). However, in-situ moisture conservation practices provide the moisture all over the growth stages of the crops and moreover improve physico-chemical and biological properties of the soil (Ngangom et al 2020). In addition, it improves aeration in the

rhizosphere which results in enhanced root growth, nodulation, and N-fixation by the Rhizobium bacteria (Sun et al 2022). Augmentation of these practices with efficient weed management options may significantly improve the crop performance which results in higher qualitative crop yields. Manual and mechanical weed management techniques are extremely successful, but they are also costly, tiresome, and time-consuming (Ram et al 2011 and Pratap et al 2023). For effective control of the weeds in the pigeonpea crop, the use of pre-and post-emergence herbicides, such as pendimethalin, imazethapyr, and quizalofop-ethyl has been recommended (Deore 2008 , Reddy et al 2016). Chemical weed management methods are more convenient, less time demanding, and less expensive, and they may offer weed-free conditions from crop plant establishment (Pratap et al 2021a, 23). Hence, the present field experiment was conducted to study the effect of land configuration and weed management options on soil fertility and nutrient uptake by pigeonpea.

MATERIAL AND METHODS

The field experiment was laid-out during *kharif* season in 2020 at the Research Farm of Indian Agricultural Research Institute, New Delhi (28.38° N, 77.18° E and 228.6m elevation). The region has a sub-tropical and semi-arid climate with a mean rainfall 650 mm, hot dry summer (March-June), wet monsoon season (July-September) and a cool winter (October-February). The soil of the experimental site was sandy loam in texture with pH 7.79, low in organic carbon 0.41%, low in available N (196 kg/ha), medium in Olsen P (13.70 kg/ha) and medium in NH_4OAc extractable K (290 kg/ha). The experiment was laid-out in a split-plot design with three land configurations *viz.* Broad bed furrow (BBF), Ridge and furrow (RF), and Flat-bed sowing (BF), in main plot and weed management practices, Weedy check (WM_1), Hand weeding twice at 30 and 60 DAS (WM_2), Metribuzin 0.25 kg/ha (Pre-em.) *fb*. [Imazethypr+Imazamox (premix)] 75 g/ha at 30 DAS (WM_3), Pretilachlor 1.0 kg/ha (Pre-em.) *fb*. [Imazethypr+Imazamox (premix)] 75 g/ha at 30 DAS (WM_4), Metribuzin 0.25 kg/ha (Pre-em.) *fb*. One manual weeding 30 DAS (WM_5), Pretilachlor 1.0 kg/ha (Pre-em.) *fb*. One manual weeding 30 DAS (WM_6) in sub-plots.

Pigeonpea variety 'Pusa Arhar-16; was sown on 27th June 2020 using a seed rate of 15 kg/ha at 45 cm row-to-row and 15 cm plant-to-plant spacing. Crop was applied with FYM @ 5t/ha and fertilized with basal dose of 30 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha through urea, single super phosphate and muriate of potash. Three irrigations were given as and when required to the crop to maintain adequate soil moisture throughout crop growth. Plant samples of crop (seed and stalk) collected at the time of harvest, were dried, processed and analyzed for analyzed for N by micro-Kjeldahl method (Jackson 1973) and N uptake was calculated by multiplying dry matter with N content (%) of plant. The P and K in plant samples were analyzed after digestion with di-acid (HNO_3: $HClO_4$ in the ratio of 10:4) by vanadomolybdo phosphoric yellow colour method and flame photometer, respectively. Soil samples (0-15 cm depth) were collected from each plot with the help of augur after crop harvest and analyzed using standard procedure (Jackson 1973). Data were suitably analysed with using SAS software of ICAR-Indian Agricultural Statistics Research Institute and evaluation was made at 5% level of significance.

Protein yield: Protein yield in seed was calculated by multiplying their respective N content with 6.25. Nutrient uptake (N, P and K) and protein yield was calculated as:

Nutrient uptake(kg/ha) = {Nutrient concentration (%) x Dry weight of stalk (kg/ha)/100}

$$\text{Protein yield (kg/ha)} = \frac{\text{Protein (\%)} \times \text{Seed yield (kg/ha)}}{100}$$

Microbial biomass carbon: The soil samples were estimated by the following protocols given by Nunan et al (1998). The soil microbial biomass carbon (MBC) was then calculated using the following formula:

$$\text{MBC (µg/g of soil)} = \frac{\substack{\text{(O.D. of fumigated soil –} \\ \text{O.D. of non fumigated soil)}}}{\text{Amount of soil used}} \times 15487$$

Dehydrogenase activity: Dehydrogenase activity was determined by measuring the rate of production of tri-phenyl formazan (TPF) from tri-phenyl tetrazolium chloride (TTC), which acts as an electron acceptor. The method used for the assay of dehydrogenase activity followed the procedure outlined by Klein et al (1971).

Alkaline phosphatase activity: Alkaline phosphatase activity in the soil was estimated as described by Tabatabai and Bremner (1969), the values are expressed in terms of µg of p-nitrophenol per gram of soil per hour (µg PNP/gsoil/hr).

Fluorescein diacetate hydrolytic activity: The fluorescein diacetate hydrolytic activity in the soil was measured following the procedure described by Green et al (2006), with values expressed in terms of µg of fluorescein per gram of soil per hour (µg FL/g soil/hr).

RESULTS AND DISCUSSION

N, P and K content in seed and stalk: The N, P and K contents in pigeonpea seeds and stalks were significantly influenced by land configuration and weed management (Table 1). Broad bed and furrow resulted in significantly higher N, P and K content in seed and stalk of pigeonpea over ridge and furrow and flatbed planting system. The nutrient

content increased because of the availability of higher soil moisture, aeration, root growth and optimum nutrients availability under broad bed and furrow, and ridge and furrow practice compared to conventional practice (flatbed). Earlier researcher also reported similar findings (Sharma et al 2018, Babu et al 2020 and Rao et al 2022). It is apparent that in weed management options, N, P and K contents in seed as well as in stalk were highest with twice hand weedings at 30 and 60 DAS (WM_2) and found superior over rest of treatment except that the phosphorus content (in seed and stalk) and potassium content in seed was statistically on par with metribuzin+hand weeding at 30 DAS (WM_5), and pretilachlor+ hand weeding at 30 DAS (WM_6). Further, higher content of N, P and K with twice hand weeding and other weed management attributed to the fact that these treatments controlled and checked the weed growth more efficiently and provided favourable environment to the crop for longer time to use moisture and available nutrients resulting in increase of N, P and K content. Komal and Yadav (2015) and Lal et al (2017) observed that maximum nutrient uptake (N, P and K) was in crop grown under broad bed and furrow, and ridge and furrow planting methods.

Protein content and protein yield: Broad bed furrow recorded significantly higher content and yield of protein in seed over FB and RF. However, protein content was statistically at par with RF (Table 1). As protein content is directly related with N content in seed and stalk, the higher protein content in BBF could be due to higher N content in seed than the other treatments. Lower protein content and yield seed was recorded in FB treatments. These findings are in agreed with those reported by Shinde (2012) and Joshi et al (2018). Amongst weed management options, as comparison to the weedy check, all weed managing techniques reported significantly greater protein content in seed. However, WM_2 recorded significantly higher seed protein content being statistically on par with WM_5 and WM_6 treatment, while maximum protein yield was obtained with WM_2 treatment which was greater over rest of treatment. This might be due to higher N content in seed, efficient weed control enabled crop higher uptake of nutrients, as a result higher seed yield and protein yield. The similar results were reported by Kohli et al (2006) and Pratap et al (2021b) that the high protein content and protein yield were mainly due to better control of weeds from the early stages of crop growth due to two hand weeding and pre-emergence application of herbicide and subsequent hand weeding or subsequent herbicide application at later stage of crop growth.

Seed and stalk yield: The maximum seed yield (1.71 t/ha) and stalk yield (4.83 t/ha) were recorded in broad bed and furrow (BBF) and found superior over the RF and FB land configuration (Fig. 1). The yield increased because of increased plant height, number of leaves, number of branches, number of pods/plant and 1000 seed weight, this might be due to the cumulative action of soil moisture, aeration and nutrients in optimum quantity under broad bed and furrow, and ridge and furrow practice compared to conventional practice (flatbed). Similar findings reported by Kantwa et al (2006), Patil et al (2016) and Rao et al (2022). Among the weed management options, the maximum seed yield (1.80 t/ha) and stalk yield (5.19 t/ha) were recorded with WM_2 (Twice hand weeding at 30 and 60 DAS) and found superior over rest of the weed management options except WM_5. Both WM_1 and WM_5 (Metribuzin + hand weeding at 30 DAS) were statistically at par with respect to both seed and stalk yield. The stalk yield was statistically at par among WM_1, WM_5 and WM_6. The minimum seeds yield was achieved in weedy check due to severe-weed competition faced by the crop. Similar results were reported by Choudhary et al (2012), Bhowmick et al (2015) and Yadav et al (2015).

N, P and K uptake by seed and stalk: The BBF showed significantly higher N, P and K uptake by seed and stalk over RF and FB, which could be attributed to higher seed and stalk yield as a result of better growing condition during crop growth period which aids in greater absorption and translocation of nutrients in different plant parts as a result of greater weed control. Jat et al (2012) and Patel et al (2013) also reported similar findings, where minimum N, P and K uptake was found under FB because of lower seed and stalk yield due to more density and dry weight of weeds results in more nutrient depletion by the weeds. Twice hand weedings at 30 and 60 DAS (WM_2) recorded higher N, P and K uptake by seed and stalk over rest of the treatments, whereas weedy check plot recorded lowest uptake of nutrient (N, P and K) (Table 2). This might be due to lower depletion of soil nutrient by the weeds due to efficient control of all weeds under two
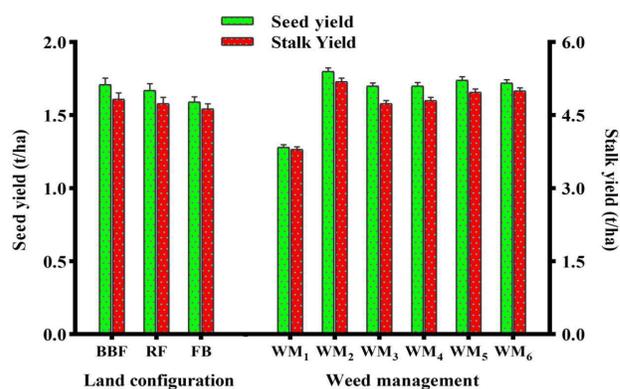

Fig. 1. Effect of land configuration and weed management practices on seed and stalk yield of pigeonpea

hand weeding and all other weed management treatments compared to weedy check apart of these leaving larger amount of nutrients for absorption and translocation in different plant parts. Vyas et al (2013), Pratap et al (2021b) and Komal and Yadav (2015) also observed higher weed density and dry matter production in weedy check allowed the weeds to deplete higher amount of nutrients from the soil.

Available N, P, K and organic carbon: Pigeonpea sown on BBF recorded significantly higher available N, P and K in soil over FB and RF except N and P which, being at par with RF.

However, no significant effect of land configuration observed on organic carbon (Table 3). This might be attributed by lower depletion of nutrients (N, P and K) by reduced weed infestation by enabling the crop to utilize growth resources more efficiently, as a result of higher weed suppression under broad bed and furrow, and ridge and furrow treatments. Among weed management options all the treatments recorded significantly higher N, P and K over WM_1 (weedy check) and WM_4 except P. However, WM_2 (twice hand weedings at 30 and 60 DAS) recorded maximum recorded higher available N, P and K in

Table 1. Effect of land configuration and weed management on NPK content in seed and stalk of pigeon pea

Treatments	N content (%)		P content (%)		K content (%)		Protein content (%)	Protein yield (kg/ha)
	Seed	Stalk	Seed	Stalk	Seed	Stalk		
Land configuration								
BBF	3.19	1.22	0.36	0.22	1.24	1.83	20.0	342.3
RF	3.12	1.20	0.34	0.20	1.21	1.77	19.7	327.9
FB	3.14	1.20	0.32	0.19	1.20	1.60	19.5	313.1
LSD (p=0.05)	0.04	0.02	0.03	0.02	0.02	0.07	0.3	5.9
Weed management								
WM_1	2.90	1.17	0.30	0.14	1.17	1.58	18.2	232.6
WM_2	3.33	1.24	0.37	0.25	1.24	1.86	20.8	375.8
WM_3	3.14	1.20	0.33	0.20	1.21	1.72	19.6	333.4
WM_4	3.11	1.19	0.32	0.18	1.20	1.68	19.5	329.9
WM_5	3.25	1.22	0.36	0.23	1.23	1.80	20.3	353.0
WM_6	3.18	1.22	0.34	0.21	1.22	1.75	19.9	341.9
LSD (p=0.05)	0.15	0.03	0.03	0.04	0.02	0.05	0.9	16.5

Table 2. Effect of land configuration and weed management on NPK uptake in seed and stalk of pigeonpea

Treatments	N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)	
	Seed	Stalk	Seed	Stalk	Seed	Stalk
Land configuration						
BBF	54.8	60.0	6.1	10.6	21.0	90.4
RF	52.5	57.6	5.7	9.4	20.3	85.3
FB	50.1	54.5	5.1	9.1	19.1	73.4
SEm±	0.2	0.4	0.1	0.2	0.1	0.9
LSD (p=0.05)	0.9	1.5	0.5	0.7	0.2	3.4
Weed management						
WM_1	37.2	43.0	3.9	5.0	15.0	58.2
WM_2	60.1	64.2	6.8	13.1	22.4	96.5
WM_3	53.4	58.4	5.7	10.3	20.6	84.2
WM_4	52.8	57.8	5.5	9.0	20.3	82.3
WM_5	56.5	60.7	6.2	11.3	21.4	90.3
WM_6	54.7	60.1	5.9	9.5	21.0	86.8
SEm±	0.9	0.7	0.2	0.6	0.2	1.2
LSD (p=0.05)	2.6	2.1	0.5	1.8	0.6	3.5

soil which was found at par with WM_3 (metribuzin + imazethapyr), WM_5 (metribuzin+ hand weeding at 30 DAS) and WM_6 (pretilachlor + hand weeding at 30 DAS). This might be possible through reducing nutrient removal by weeds because of efficient control of weeds during crop period. These findings are in close with findings of Pratap et al (2021a).

Soil biological properties: Both land configuration and weed management practices influenced biological properties significantly (Table 4). The broad bed and furrow (BBF) recorded significantly higher soil microbial biomass carbon (SMBC), dehydrogenase activity (DHA), alkaline phosphatase activity (ALP) and fluorescein diacete

hydrolysis (FDA) over FB treatment. However, DHA, ALP and FDA were at par with RF treatment except SMBC. The flatbed sowing has lowest soil biological activity. It could be due to FYM application, leaf drop, low C:N ratio and legume effect in tillage practices which might have led to higher microbial and enzymatic activities. The similar result reported by Tao et al (2009), Dodor and Tabatabai (2003), Perez-Brandan et al (2012) and Gajda et al (2013). Among weed management options significantly higher SMBC, DHA and ALP were in WM_2 which were at par with WM_5 except SMBC which was also at par with WM_3 and WM_6. However, FDA activity significantly higher in WM_2 over rest of other treatments. The

Table 3. Effect of land configuration and weed management on available NPK and organic carbon in soil after harvest of crop

Treatments	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Organic carbon (%)
Land configuration				
BBF	218.9	16.8	263.9	0.42
RF	210.5	16.0	249.5	0.42
FB	200.0	15.2	237.0	0.41
SEm±	2.6	0.2	2.7	0.02
LSD (P=0.05)	10.3	0.8	10.8	NS
Weed management				
WM_1	178.1	14.1	220.4	0.41
WM_2	227.5	17.0	268.6	0.42
WM_3	214.9	16.4	252.3	0.41
WM_4	206.3	15.7	247.7	0.42
WM_5	220.5	16.8	260.1	0.42
WM_6	211.4	16.1	251.5	0.42
LSD (P=0.05)	18.3	1.5	18.7	NS

Table 4. Effect of land configuration and weed management on the soil microbiological properties of soil after the harvest of pigeon pea crop

Treatments	SMBC (µg C/g soil)	DHA (µg TPF/ g soil/24 hr)	ALP (µg p-NP/g /hr)	FDA (µg FL/ g soil/hr)
Land configuration				
BBF	253.3	225.8	285.8	0.61
RF	214.5	216.0	274.2	0.59
FB	191.3	197.5	252.5	0.47
LSD(P=0.05)	33.1	14.5	16.0	0.03
Weed management				
WM_1	187.3	176.7	228.3	0.46
WM_2	241.6	235.8	294.1	0.68
WM_3	217.4	213.1	274.0	0.53
WM_4	207.7	209.7	265.8	0.50
WM_5	235.6	225.9	288.8	0.61
WM_6	228.5	217.4	273.8	0.57
LSD (P=0.05)	29.9	11.7	13.9	0.02

least biological activity was with weedy check (WM$_1$). The effects of stimulation or inhibition of the above activity because of application of various pesticides have been reported in numerous studies (Das and Varma, 2011, Jinger et al 2016, Lal et al 2017 and Rasool et al 2014).

CONCLUSION

Thet broad bed and furrow practice improve OC, available N, P, K and soil biological properties in soil as well as total N, P, K and protein content, protein yield and uptake by the crop which significantly superior over ridge and furrow and flatbed method. The twice hand weeding given at 30 and 60 days after sowing proved superiority in terms of OC, available N, P, K and soil biological properties in soil as well as N, P, K and protein content, protein yield and uptake by the crop.

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Alleviation of Drought Stress by ACC (1-amino cyclopropane -1-carboxylate) Deaminase Producing Plant Growth Promoting Rhizobacteria Isolates in *Capsicum annum.* L

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Abstract: Plant growth promoting rhizobacteria (PGPR) with multiple PGP traits and ACC deaminase activity have additional advantage to mitigate drought stress. Strains with these characters and resistant to drought conditions could be hypothesized to be efficient isolates to overcome drought stress. The present study shows the ability of two such isolates IS-7 (*Bacillus halotolerans*) and IS-74 (*Enterobacter hormaechei*) to help the capsicum plants sustain even severe drought conditions (12.5% WHC). Comparatively, both the isolates were able to make the plant sustain drought but with decreased shoot and root wet and dry weights, root volume, root shoot ratio, leaf number and chlorophyll content. However, significant difference was not observed between control plant without drought and inoculated + drought induced plants at 50% WHC. Control plants subjected to drought and without isolates could not survive 50% WHC drought severity. Plant responses to defend against reactive oxygen species (ROS) was more accelerated in the activity of enzymatic (increased -SOD, APOX, GPOX, MDA and decreased- GR and NR) and non-enzymatic (proline) antioxidants. Elevated morphological and biochemical status indicate the positive effect of the isolates compared to control without treatment.

Keywords: ACC deaminase, PGPR, Drought stress, Antioxidants, *Capsicum annum*

Agricultural production has been a major challenge owing to the significant changes in climatic conditions like drought, salinity, modified monsoon and global warming (Chen et al 2014). Consequently, plants undergo abiotic and biotic stress, among which drought and salinity greatly effect on growth and development of plants in arid and semi-arid regions (Mohammadizad et al 2013). Among various environmental stresses drought stress stands first in reducing plant growth and productivity. Different studies indicate that the global population may increase by 9.2 billion by 2050 and food demand may further increase in the next decades (Silva 2018). To address the said need modern, sophisticated and sustainable agricultural strategies are required. For the last three decades, usage of commercial fertilizers and pesticides has been very intense causing adverse effects on human health and the environment (Hahn 2014).

During drought stress, plants are negatively affected, leading to changes in morphology and physiology due to the generation of reactive oxygen species (ROS) (Hossain and Dietz 2016, Chandra et al 2019) and an increased oxidative damage. To counteract this, plants developed defence using enzymatic - superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), nitrate reductase (NR), malondialdehyde (MDA) etc. and non-enzymatic protectants (proline, cysteine, glutathione

etc.) as evident from recent studies, adverse effects of drought on plants is mitigated by the use of PGPR having ACC deaminase activity (Tiwari et al 2018, Singh et al 2019). Along with oxidative damage, an increased production of ethylene is observed in plants during stress leading to damage to plants. The negative effects of drought stress (ethylene production and oxidative damage) can be bypassed by the use of ACC deaminase-producing PGPR which can degrade the ACC to α-ketobutyrate and ammonia to reduce levels of ethylene and increase the non-enzymatic and enzymatic antioxidant machinery in the plant. Hypothetically, PGPR is the way to use as a biofertilizer and bio inoculant to alleviate drought stress and meet global food needs (Glick 2014). Recently, *Bacillus* and *Enterobacter* species are reported for their ability in tolerating extreme environments, acting on phytopathogens and as plant growth promoters (Tzipilevich et al 2021, Ajibade et al 2023). Chilli (*Capsicum annum.* L) is a crop that grows in the tropical regions of America and later spread across the world. Chilli, the hot pepper is one of the most valuable commercial crops grown in India. Due to its long history of cultivation, out-crossing nature and popularity of the crop, large genetic diversity including local landraces has evolved in India. Chilli is mostly grown under rain-fed cultivation and the crops are often affected by low moisture stress leading to inconsistent yield and quality. Hence, the present study is mainly focused

on the effect of PGPR isolates *Enterobacter hormaechei*, and *Bacillus halotolerans* on the growth of chilli under various drought severities.

MATERIAL AND METHODS

Screening of PGPR bacteria: The rhizosphere soils of chilli were collected from five different locations in Jadcherla Taluka (16.769968" N, 78.148212" E), Mahabubnagar district of Telangana State, India. The soil samples were carefully taken into sterilized plastic covers, brought to the laboratory, and stored at 4°C. From these soils pure cultures were isolated on Cr-YEMA, Jensens's and Kings-B media and screened for PGPR traits, production of Indole acetic acid (IAA), Phosphate solubilisation, siderophore activity, HCN production, Gibberellic acid production, Nitrogen fixation and ACC deaminase activity (Khalid et al 2004, Kumar et al 2012).

Screening of drought tolerant bacteria: Isolates exhibiting a greater number of PGPR traits, including ACC-Deaminase activity, were evaluated for their capacity to grow in the presence of 40% PEG-6000. The log phase cultures were introduced into nutrient agar supplemented with varying concentrations of PEG-6000 (10, 20, 30 and 40%). The optical density at 600nm was subsequently measured after 24 hours of incubation.

Molecular characterization: The selected bacteria obtained in pure form were cultivated in nutrient broth under controlled conditions (30-32°C for 24 hours). Genomic DNA was extracted from the cultures using the Genomic DNA Extraction kit (Thermo-scientific), following the standard protocol. Subsequently, a 16S rRNA gene fragment of approximately 1500 base pairs was amplified through PCR using universal primers. The resulting sequences were then subjected to a BLAST search in the NCBI (https://www.ncbi.nlm.nih.gov/) database for phylogenetic identification.

Experimental details: The chilli seeds were surface sterilized using 75% ethyl alcohol (1 min), 1% sodium hypochlorite (30 secs) and washed in sterile water for 5-6 times. A bacterial broth culture of selected isolates (5 x 10^6 CFU) was obtained and mixed with sterile seeds along with CMC as adhesive and was air dried. After seed germination in pots (15 cm) filled with 4 kg of sterile red loamy soil, pots were watered regularly until they reached four leaf stages. Later a greenhouse-based factorial experiment was conducted using a completely randomized block design, with each treatment replicated three times. The experimental treatments consisted of varying soil water holding capacities (WHC) at 75, 50, 25 and 12.5%. The soil's WHC had been previously determined following established procedures

(Nejad et al 2023). Two control groups were established: Control 1, which involved no PGPR and drought stress, and control 2, which included no PGPR application and without drought stress.

Measurement of morphological characters: Following the harvest, an array of morphological characters, including shoot length, root length, leaf count, leaf area, fresh shoot weight, dry shoot weight, fresh root weight, dry root weight, and root volume, were carefully measured. To determine the dry weights, plant samples were subjected to drying in a hot air oven at a temperature of 70°C for a duration ranging from 24 to 48 hours, ensuring complete desiccation.

Estimation of chlorophyll: One gram of fresh leaf sample was cut into small discs and placed in a test tube containing 5 mL of dimethyl sulfoxide (DMSO). After incubation, the absorbance was measured using a spectrophotometer at wavelengths 645 nm and 663 nm, with DMSO serving as the blank (Arnon 1949).The calculations for chlorophyll content were performed as follows

- Chlorophyll a (mg/g) = (12.7 × A663) - (2.59 × A645)
- Chlorophyll b (mg/g) = (22.9 × A645) - (4.7 × A663)
- Total chlorophyll (mg/g) = (8.2 × A663) + (20.2 × A645)

Soluble carbohydrates: Homogenate one gram of fresh leaves was made using a mixture of ethanol, chloroform, and water in a ratio of 60:25:15 (v/v). The resulting mixture was incubated at 60°C for duration of 2 hours. Subsequently, the samples were subjected to centrifugation at 10,000 rpm for 30 minutes to separate the components. A 0.2 mL portion of the supernatant was then adjusted to a total volume of 1 mL with distilled water and combined with 1 mL of a 5% phenol solution and 5 mL of 96% H_2SO_4. Soluble carbohydrates were determined against glucose standard curve at 490 nm (Dubois et al 1951).

Relative water content (RWC) : In a clean Petri plate take one gram of finely cut fresh leaves (circular discs) were immersed in 25 mL of distilled water for a 6-hour period and then the leaf samples were gently dried by blotting and weighed. Subsequently, the leaves were subjected to oven drying at 70°C for 24 hours, and their final weight was documented (González and González 2001).

RWC = (Fresh Weight - Dry Weight) / (Saturated Weight - Dry Weight) × 100.

Ammonia production: In the tubes containing freshly grown bacterial cultures (24hrs), 0.5 mL of Nessler's reagent was added. The presence of a light-yellow colour (+) and a deep yellow to brown colour (++) indicate the production of ammonia (Dye 1962).

Protease production: Protease production was assessed through a spot inoculation method, where log-phase bacterial cultures were individually placed on Skim Milk Agar

(SMA) medium. This medium comprised 5.0 grams of casamino acids, 2.5 grams of yeast extract, 1.0 gram of glucose, 100 millilitres of skim milk solution, and 15 grams of agar-agar, all adjusted to a pH of 7.0. The inoculated plates were then incubated for a period of 4-5 days at a temperature of 30°C. Identification of bacterial isolates capable of producing protease was achieved by observing the formation of a halo zone surrounding the bacterial colony (Maurhofer et al 1994).

β – 1, 3 – Glucanase assay: The β-glucanase activity of specific bacterial isolates was assessed through the utilization of β-glucan agar, following the plate method with Congo red staining. The presence of a distinct halo zone surrounding the bacterial colony was an indication of β-glucanase production (Teather and Wood 1982).

Chitinase production: For the chitinase enzyme assay, a reaction mixture that consists of 0.25 ml of the supernatant (enzyme source), 0.3 ml of sodium acetate buffer at pH 5.3, and 0.5 ml of 0.1% colloidal chitin was made. After incubation of this reaction mixture in a water bath at 50°C for 4 hours, 1 ml of a DNS reagent was added. The mixture was boiled and 1 ml of a 40% Rochelle salt (sodium potassium tartrate) solution was added and cooled in running tap water. The development of a purple colour in the reaction mixture signifies the presence of reducing sugars and, consequently, the presence of chitinase enzyme (Legrand et al 1987).

Total proline: The homogenate was made with one gram of fresh leaves, 10 ml of 3% sulfosalicylic acid and centrifuged at 10000 rpm for 10 min at 4°C. To 1ml supernatant 2 ml of each ninhydrin, glacial acetic acid was added and incubated at 100^0 C for 1 hr. The contents were cooled immediately and 4 ml of toluene was added and incubated in dark (20 min). Optical density was read at 520nm and proline content was estimated using a proline standard curve (Bates et al 1973)

Lipid peroxidation or malondialdehyde (MDA): One gram of fresh leaves was ground and then mixed with 10 ml of a solution containing 0.25% thiobarbituric acid (TBA) in 10% trichloroacetic acid (TCA). The resulting mixture was subjected to incubation in a water bath at 95°C for 30 minutes and was then immediately transferred to an ice bath to cool. After cooling, the mixture was centrifuged at 10,000 rpm for 15 minutes at 25°C to separate the solution. The optical density of this solution was measured at two wavelengths, specifically at 532 nm and 600 nm (Davenport et al 2009).

$$MDA \ (\mu \ moles/g \ of \ FW) = \frac{Abs \ 532 – Abs \ 600)}{Extinction \ coefficient} \ x \ 1000$$

Evaluation of Antioxidant enzyme activities: To assess superoxide dismutase (SOD), the method established by Beauchamp and Fridovich (1971) was employed. As for ascorbate peroxidase (APX), the protocol developed by Nakano and Asada (1981) was used. Guaiacol peroxidase was quantified by the methodology described by Castillo et al (1984).

Catalase activity: Enzyme extract (0.1 ml) was mixed with 100 mM phosphate buffer (pH 7.0) and 0.5 ml of a 75 mM hydrogen peroxide (H_2O_2) solution. The reaction mixture was completed by adding 950 µl of distilled water. Subsequently, the optical density (OD) at 240 nm was measured (Aebi 1974).

Nitrate reductase activity: Plant leaf material (0.5 grams) was ground in 1 ml of a 50 mM potassium phosphate buffer (pH 8.0) containing 1 mM EDTA, 25 mM cysteine, and 3% (w/v) BSA. Enzyme sample was obtained from the supernatant after centrifugation (12,000 rpm, 20 minutes, 40°C). The reaction mixture was made with 200 µl of 50 mM potassium nitrate, 200 µl of 0.5 mM NADH, 400 µl of the enzyme extract, and 1,200 µl of 50 mM potassium phosphate buffer (pH 7.0) and incubated for 15 minutes at 25°C. Absorbance of the pink coloured complex formed was measured at 540nm (Hageman and Hucklesby 1971)

Glutathione reductase activity: Mixture of 10 mM potassium phosphate buffer, 0.5 mM 5, 5 dithiobis-2-nitrobenzoic acids (DTNB), 2.0 mM NADPH, 0.33 mM EDTA, 0.1 ml of enzyme extract, and 20mM GSSG (oxidised glutathione) was made. Double distilled water was added to make up the solution to 3 ml. Optical density was read at 412 nm after development of red colour in tubes (Gutteridge and Halliwell, 2000).

Statistical analysis: The data were subjected to statistical analysis using Fischer's one-way with the help of SPSS software version 24.

RESULTS AND DISCUSSION

The rhizosphere soils of capsicum collected from five different locations from which fifteen isolates were obtained in pure culture and were evaluated for PGPR traits (Table 1). The presence of multiple traits are being recently studied for selecting efficient isolates (Singh et al 2010, Anuradha et al 2022). Among the fifteen isolates, IS-7, IS-74 expressed more number of PGP traits than other strains. In the present study, presence of more number of PGPR traits was considered as criterion for selecting efficient PGPR isolate.

The selected isolates with PGPR traits were further evaluated for drought tolerance by growing in a media amended with PEG-6000 at 10, 20, 30 and 40%. Isolates able to grow in the presence of different concentrations of amended PEG 6000 are considered to be resistant to drought stress (Michel and Kaufmann 1973). All the isolates

could grow at 40% PEG except IS-8 and IS-91 (Table 2). Isolates IS-7, IS-93, IS-27 and IS-74 were showing more tolerance and higher OD. Even though, IS-93 and 27 were tolerant than IS-74, owing to the number of PGPR traits as innate character, IS-7 and IS-74 were selected for further study and were found to be efficient pant growth promoters in chilli plant experiment .

The selected isolates, IS-7 and IS-74 were further evaluated for their ability to express PGPR traits even in presence of 40% PEG 6000 amended media. Under stressed conditions isolates may lose the ability to show the required PGPR trait (Ahmad et al 2022). Both the isolates could express the traits at 40% PEG. With the increase in PEG concentration, there is a decrease in quantitative production of IAA, 'P' solubilisation and ACC deaminase activity. Compared to IS-74, IS-7 was more efficient at 40% PEG (Table 3). IS-7 could retain the ability of siderophore and

glucanase production even at 40% PEG but lost the ability to produce HCN whereas, IS-74 couldn't retain the ability to show siderophore, ammonia production, protease and glucanase activity at 40% PEG (Table 4).

Both selected PGPR isolates (IS-7 and IS-74) were experimentally analysed for their ability to ameliorate different drought severities (Table 5). Both the isolates could make the plant sustain even severe drought conditions (12.5 % WHC) whereas, control plant subjected to drought and without PGPR inoculation couldn't survive 50% WHC drought. There was significant decrease in plant growth parameters such as shoot/root length, fresh and dry weights and root volume is observed in plants stressed with drought stress conditions. This could be due to variations in physio biochemical levels because of water limitation. Similar observations were made in plants like *Helianthus annus* L (Abdel Razik et al 2021) and *Brassica napus* (Shafiq et al

Table 1. Characterization of PGPR traits of selected isolates from rhizosphere soils of *Capsicum annum*. L

Area	Media	Isolates No.	IAA	Siderophore	N2Fixation	P' solubilization	HCN	GA	ACC deaminase
Avancha	CR-YEMA	IS-7	+	+	--	+	+	--	+
	Jensen	IS-8	--	+	--	--	--	--	+
	Kings - B	IS-9	+	+	--	+	--	--	--
Gangapur	CR-YEMA	IS-25	--	+	--	+	--	--	+
	Jensen	IS-26	+	+	+	--	--	--	+
	Kings - B	IS-27	--	+	--	--	--	--	+
Rangareddyguda	CR-YEMA	IS-73	--	+	--	--	--	--	+
	Jensen	IS-74	+	+	-	+	--	--	+
	Kings - B	IS-75	+	+	--	--	--	--	--
Alwanpally	CR-YEMA	IS-79	--	--	--	--	--	--	--
	Jensen	IS-80	+	+	+	-	--	+	+
	Kings - B	IS-81	--	--	--	--	--	--	--
Thimajipet	CR-YEMA	IS-91	+	+	--	--	--	--	+
	Jensen	IS-92	--	--	+	--	--	--	+
	Kings - B	IS-93	+	+	--	--	+	--	+

Table 2. Optical density values of different isolates at 600nm were measured in PEG-6000 amended nutrient broth

Isolate No	Polyethyleneglycol				
	0%	10%	20%	30%	40%
IS-7	1.029	0.973	0.457	0.273	0.098
IS-8	1.637	0.891	0.515	0.236	0.000
IS-26	1.207	0.732	0.463	0.287	0.007
IS-27	0.729	0.532	0.376	0.220	0.058
IS-74	1.432	0.826	0.441	0.276	0.024
IS-80	0.963	0.641	0.473	0.258	0.012
IS-91	1.405	1.200	0.863	0.187	0.005
IS-93	1.000	0.993	0.429	0.170	0.087

2014). In chilli total biomass reduction is due to decrease in turgor pressure (Chuyong and Acidri 2017). In general, there was not much significant difference between various morphological characters studied and control (un inoculated and no drought) up to 50% WHC severity which indicates that both the isolates could make the plant survive without much damage up to 50% WHC. The low shoot root ratio indicates higher transpiration and a higher ratio indicates more absorption of nutrients from soil and thereby increase shoot biomass and probably increase plant resistance to drought. This ratio is proportional to nutrient supply and fertilization (Kang and Van Iersel 2004). In the present study higher root shoot ratios were observed in plants treated with IS-7 compared to IS-74.

With the increase of drought severity there was decrease in the parameter studied (Table 6). Organic carbon is stored in the form of total soluble sugars which stands as an important feature for maintaining osmotic potential, plays a role in osmotic regulation and maintains osmotic pressure. Plants that accumulate more of the total soluble sugars in response to drought stress effectively regulate osmosis (Slama et al 2007). Chlorophyll a, b, total chlorophyll, total soluble carbohydrates and relative water content (RWC) significantly decreased compared with control at 100% WHC. However, inoculation of IS-7 and IS-74 could maintain adequate amounts of above said parameters even at severe drought (12.5% WHC) and sustain growth. Similar results were observed in *Zea mays*, where PGPR could increase the photosynthetic pigments compared to un inoculated control under drought stress (Yasmin et al 2017).

Drought stress triggers several complex mechanisms in order to defend from adversities caused by the ROS generated. Many protective and defensive physiological systems like scavenging of excessive ROS, production of low molecular weight nitrogenous compounds etc. are important in minimizing deleterious effects. Effective destruction of excess ROS require synchronous activity of many antioxidant enzymes (Gul et al 2022). SOD is a strong oxidant which oxidizes thiol groups in to OH radicals. Hydroxyl radicals are further converted to water and molecular oxygen by catalase and peroxisomes. Mittler

(2002) has reported that dynamic levels of ROS are maintained in plants because of balance between SOD, POX and CAT etc. Enzymatic antioxidants like APOX, GPOX, SOD, CAT, MDA and non-enzymatic proline was estimated to understand the role of isolates in overcoming adversities from ROS (Table 6). In general, with the increase in drought there was an increase in quantities of all the enzymes possibly to overcome stress injury indicating the positive role of isolates inoculated. In contrast to this NR and GR decreased. Accumulation of proline and antioxidant enzymes in drought stressed plants was also recently reported in sweet pepper (Iqbal et al 2023). Similarly, enzyme activity of APOX, GPOX, SOD, MDA increased at the highest severity of water deficit and this was more seen in plants treated with IS 7 than IS 74 except for CAT activity. The degree of peroxidation of membrane lipids due to ROS is reflected in by product MDA (Lacan and Baccou 1998). Studies have shown that the levels of MDA increased with the increase in ROS in drought stressed phenotypes (Soureshjani et al 2019). Both GR and NR can be important indicators of metabolic and physiologic status of plant in water deficit conditions. Balance of redox potential in cells is achieved by the activity of GR which catalyse the conversion of reduced and oxidized glutathione and in turn helps in scavenging ROS and protect plant (Guo et al 2018). Nitrate reductase activity is involved in nitrate assimilation; plant acquisition of mineral nutrients helps in neutralizing adverse effects of drought stress (Caravaca et al 2003). In the present study decreased activity was observed even in higher severities, which may be due to decreased stress by the activity of inoculated isolates.

Table 4. PGPR properties at PEG 40%

PGPR traits	IS - 7		IS - 74	
	Control	40% PEG	Control	40% PEG
HCN production	+	--	--	--
Siderophore production	+	+	+	--
Ammonia production	--	--	+	--
Chitinase activity	--	--	--	--
Protease activity	--	--	+	--
β-1,3 glucanase activity	+	+	+	--

Table 3. PGPR properties at PEG 40%

PGPR traits	IS- 7			IS- 74			CD at 0.05	CD at 0.01
	Control	30 % PEG	40% PEG	Control	30% PEG	40% PEG		
Indole acetic acid (mg/ml)	13.68	5.12	0.22	10.86	4.27	0.79	5.44	7.53
P - solubilization (mg/100 ml P_2O_5)	12.84	1.76	0.21	8.62	1.26	0.04	5.35	7.40
ACC deaminase activity in µmol α- KBA (mg/h)	8.52	4.25	1.02	9.34	5.12	2.12	3.36	4.65

Table 5. Effect of selected PGPR isolates for plant growth promotion in *Capsicum annum*. L subjected to drought stress

Isolate No.	WHC %	Shoot length (mm)	Root length (mm)	Shoot Wt. Wt. (gm)	Shoot dry Wt. (gm)	Root Wt Wt. (gm)	Root dry Wt. (gm)	Root volume (cm3)	Root shoot ratio
IS-7	75	30.62[a]	15.62[a]	58.6[bc]	26.32[b]	8.23[ab]	3.98[a]	0.31[ab]	0.15 (22.79)[a]
	50	20.42[c]	12.88[b]	52.82[bc]	21.81[b]	6.87[bc]	3.02[b]	0.24[b]	0.13 (21.13)[ab]
	25	19.86[c]	10.26[c]	45.21[c]	20.16[b]	5.23[c]	2.81[b]	0.18[bc]	0.13 (21.13)[ab]
	12.5	18.42[c]	9.74[c]	22.94[d]	9.72[c]	4.28[c]	1.74[c]	0.10[c]	0.17 (24.35)[a]
IS-74	75	29.64[a]	12.41[b]	65.66[ab]	30.12[b]	9.64[a]	3.34[ab]	0.25[b]	0.11 (19.37)[b]
	50	26.72[ab]	11.86[bc]	62.02[bc]	29.44[b]	8.2[ab]	3.02[b]	0.20[bc]	0.1 (18.43)[b]
	25	20.46[c]	10.22[c]	54.68[b]	23.62[b]	5.29[bc]	2.08[bc]	0.12[c]	0.08 (16.43)[b]
	12.5	18.86[c]	8.64[c]	24.25[d]	10.86[c]	3.14[c]	1.16[c]	ND	0.1 (18.43)[b]
Control	FC	32.68[a]	12.94[b]	80.74[a]	39.88[a]	8.68[ab]	3.92[ab]	0.38[a]	0.09 (17.46)[b]
CD at 0.05		5.53	2.08	18.29	9.23	2.18	0.94	0.12	2.53
CD at 0.01		7.49	2.81	24.79	12.50	2.95	1.27	0.16	3.43

*Values are significant at P<0.05 as per Fisher's test, values super scribed by same alphabet are not significantly different at P<0.05, Values in the parenthesis are arc sin transformed

Table 6. Effect of selected PGPR isolates for plant growth promotion in *Capsicum annum*. L subjected to drought stress

Isolate No.	WHC %	No. of leaves (Plt^{-1})	Leaf area (mm^2)	Chlorophyll A (mg g^{-1} FW)	Chlorophyll B (mg g^{-1} FW)	Total chlorophyll (mg g^{-1} FW)	Total soluble carbohydrates (mg g^{-1} DW)	Relative water content (RWC)
IS-7	75	20.64[b]	1798.62[b]	18.36[ab]	1.94[a]	42.88[ab]	0.49[a]	52.96[a]
	50	19.82[bc]	1424.26[bc]	12.42[c]	1.86[a]	30.76[b]	0.34[bc]	30.42[bc]
	25	13.64[c]	1064.22[bc]	9.78[cd]	1.34[b]	17.74[bc]	0.3[bc]	29.92[bc]
	12.5	9.82[c]	746.86[c]	6.84[d]	1.08[b]	10.86[c]	0.23[c]	17.84[c]
IS-74	75	27.78[a]	2964.32[a]	19.38[a]	1.66[ab]	46.76[a]	0.5[a]	51.68[a]
	50	20.42[bc]	1924.82[b]	13.64[c]	1.09[b]	38.42[ab]	0.42[b]	42.24[b]
	25	16.68[bc]	1730.2[bc]	9.86[cd]	0.94[bc]	18.74[bc]	0.37[b]	23.78[c]
	12.5	12.14[c]	842.16[bc]	7.64[d]	0.53[c]	12.46[c]	0.34[bc]	21.48[c]
Control	FC	28.24[a]	4024.12[a]	14.42[bc]	1.8[ab]	51.86[a]	0.56[a]	60.95[a]
CD at 0.05		6.58	1033.18	4.31	0.50	14.59	0.13	15.18
CD at 0.01		8.91	1400.10	5.84	0.67	19.78	0.18	20.57

* Figures with same alphabet are not significantly different at P<0.05

Table 7. Effect of selected PGPR isolates for plant growth promotion in *Capsicum annum*.L subjected to drought stress

Isolate No.	WHC %	APOX (Unit mg^{-1} protein)	GPOX (Units mg^{-1} protein)	SOD (Units mg^{-1} protein)	catalase (Units mg^{-1} protein)	MDA (n mol g^{-1}FW)	NR (mgN0$_2$ g^{-1} h^{-1})	GR (m mol NADPH min^{-1}g^{-1}FW)	Total Proline (uMg^{-1})
IS-7	75	12.68[cd]	0.42[c]	152[c]	1.57[c]	18.8[b]	1876[ab]	5[ab]	5.2[cd]
	50	14.34[c]	0.57[ab]	176[bc]	1.84[bc]	21.9[b]	1042[bc]	4.2[ab]	6.24[c]
	25	18.26[a]	0.64[ab]	204[bc]	2.32[ab]	32.6[ab]	987[bc]	2.8[b]	7.04[ab]
	12.5	20.42[a]	0.73[a]	274[a]	2.6[ab]	35.2[a]	727[c]	1.2[c]	7.52[a]
IS-74	75	11.68[d]	0.39[c]	148[c]	1.34[c]	18.4[b]	1465[b]	4.6[ab]	5.16[cd]
	50	12.94[c]	0.5[b]	190[bc]	1.86[b]	22.7[b]	935[bc]	3.4[b]	5.88[bc]
	25	14.66b[c]	0.62[ab]	224[ab]	2.14[b]	26.2[b]	867[c]	1.8[bc]	6.42[b]
	12.5	17.24[ab]	0.68[a]	268[a]	2.76[a]	30.4[ab]	625[c]	0.9[c]	6.89[ab]
Control	FC	9.28[d]	0.23[c]	132[c]	1.13[c]	16.2[b]	2426[a]	5.9[a]	4.62[d]
CD at 0.05		3.41	0.17	50	0.56	6.59	579	1.74	0.99
CD at 0.01		4.61	0.23	68	0.76	8.94	785	2.36	1.34

* Figures with same alphabet are not significantly different at P<0.05

Proline is reported to act as an OH radical scavenger, as a solute to protect macromolecules and reduces acidity in cells (Mundada et al 2021). With the gradual increase in drought, proline content also increased and this was more pronounced in IS-7 compared to IS-74. Accumulation of more soluble total sugars and proline could be responsible to less stress injury owing to evolving a mechanism to maintain favourable water gradient and water entry in roots (Bouremani et al 2023). The pure cultures of IS-7 and IS-74 subjected for genomic DNA isolation for 16s r RNA characterization and sequence data was obtained with the help of universal primers. The obtained sequences are set for BLAST analysis in NCBI website and established phylogenetic relationship IS-7 as *Bacillus halotolerans* (Accession No. OR593309) and IS-74 as *Enterobacter hormaechei* (Accession No. OR593312).

CONCLUSIONS

Plant growth promoting isolates with ACC deaminase activity is an added advantage to mitigate drought stress conditions. The presence of multiple PGPR traits helped the plants for plant growth promotion and helping the plant overcome negative effects by way of acquiring nutrients and maintaining proper balance of redox potentials. The selected isolates, IS-7 (*Bacillus halotolerans*) and IS-74 (*Enterobacter hormaechei*) were found to ameliorate deleterious effects of drought stress even under 12.5% WHC of pot soil which is remarkable. Both the isolate were copious producers of exopolysaccharides which helped in retaining water for longer periods and requires further evaluation. Both the isolates were found to be efficient for sustenance of capsicum under severe drought conditions at green house experiments. However, field level evaluation experiments are underway to determine their full potential.

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Principal Component Analysis of Morphological Characters in Groundnut Germplasm (*Arachis hypogaea* L.) under Dry Land Ecosystem of India

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Abstract: To determine the principal component (PC) for ten quantitative attributes, the present experiment used 45 genotypes of groundnut during *kharif* season 2019 at S.K.N College of Agriculture, Jobner. To eliminate the diversity between the groundnut genotypes, ten characteristics was used in PCs. Out of ten, only six principal components (PC1 to PC6) exhibited more than 0.5 eigen value and showed 99.44% total variability among the characters. These six PCs were given due importance for further explanation. The best genotypes were those that were found on the extreme positive side of both axes, namely genotypes RG 578 (2.74), RG 575-1 (2.38), RG 642-1 (1.70), RG 623 (1.29) along PCA I axis and genotypes RG 639 (2.79), RG 633-1 (2.69), RG 632 (1.75), and RG 625 (1.68) along PCA II axis. These genotypes will may be used for advance hybridization programme.

Keywords: Diversity, Dry land, Eigen values, Groundnut, Principal component analysis

Groundnut (*Arachis hypogaea* L.) is one of the most significant oilseed crop in India and is a Brazil native. It is grown in nearly 100 countries of the world. Major groundnut producer countries in the world are China, India, Nigeria, USA, Indonesia and Sudan (Zaman et al 2010). In India, it is cultivated over an area of 57.50 lakh hectares and producing a total of 101.10 lakh metric tonnes (Anonymous, 2022). Pod yield is a complex trait and is reportedly associated with a number of component traits. These traits are themselves inter-related. Selection for pod yield can only be effective if the desired genetic variability is present in a genetic stock. However, the development of improved plant cultivars is restricted mainly due to narrow genetic pool, which results into limited possibility to restructure the groundnut crop. Therefore, a technique is required for systematic reduction and summarization of data sets (Tanwar and Bisen 2017). Principal component analysis analyzes the data in which observations are described by several inter- correlated quantitative dependent variables, (Abdi and Williams 2010). PCA is a well-known method to identify the minimum number of components, which can explain maximum variability out of the total variability and also to rank germplasm on the basis of PC scores. The present designed with an objective to identify the minimum number of components, which can explain maximum variability out of the total variability and also to rank 45 groundnut germplasm on the basis of PC scores.

MATERIAL AND METHODS

Forty-five genotypes of groundnut were procured from the Rajasthan Agricultural Research Institute Jaipur, Rajasthan. During the *kharif* season of 2019, the genotypes of groundnut were assessed using randomized block design with three replications. Each genotype was planted in a 4.0 × 0.80 m plot with two rows that were 40 cm apart from one another. Plants were kept 15 cm apart from one another. Five plants were chosen at random from each genotype and replication to record observations on ten characteristics such as pods per plant, dry pod yield per plant, shelling percentage, solid mature kernel, biological yield per plant, harvest index and kernel yield per plant. However, observations on days to 50% flowering, days to maturity and 100-kernel weight were recorded on a plot-by-plot basis. Principal component analysis (PCA) is a standard tool in modern data analysis because it is a simple, non-parametric method for extracting relevant information from confusing data sets (Massay,1965, Jolilffle 1986) and transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The STAR (IRRI 2014) and XLSTAT (Addinsoft 2020) programmes were used to analyzed the PCA, scree plot, PCA plot, and scatter plot.

RESULTS AND DISCUSSION

Principal Component Scores (PCs) were used to dividing 45 groundnut genotypes into subgroups because most of the information from the original variables was stored in a few numbers of PCs. (Syafii et al 2015 and Dudhe et al 2018).

The first three PCs (PC1, PC2 and PC3) were responsible for 76.95% of the total variation. The first PC has the highest eigen value (3.975), explaining 39.75 percent of the variation. The remaining two PCs (PC2 & PC3) explained 22.13% and 15.07% of individual variance and 61.88% and 76.95% of cumulative variation (Table 1, Fig. 1). PCs with eigen values less than one were declared non-significant and so discarded since they are unlikely to have any practical significance (Mustafa et al 2015, Hlanga et al 2022).The majority of the variability in the set of all PCs was provided by PC1, while the remaining PCs tended to exhibit less variance. Like outcome was obtained by Mubai et al (2020) and Talekar et al (2022).

Factor loading of various characters: The factor loadings of various variables computed via PCA. In the first PC, days to 50% flowering, days to maturity, solid mature kernel had contributed greatest of the variation with positive significant coefficients of 0.1386, 0.1375 and 0.0556 respectively. Biological yield per plant also found positive coefficient (0.0204) which had contributed to the principal axis one and all remaining traits has negatively contributed to the principal axis one. High positive coefficients were for the days to 50% flowering (0.5304), days to maturity (0.5272) and 100-kernel weight (0.2689) in the second principal axis. Shelling (-0.3637), solid mature kernel (-0.3283) and biological yield per plant (-0.2857) exhibited a negative impact on the second principal axis. In the third principal axis, 100-kernel weight (0.3462) and biological yield per plant (0.1155) had the highest co-efficient values, whereas all other remaining traits were shown highly negative contribution (Table 2, Fig. 2).

PC score of germplasm: Three axes like X, Y, and Z were taken into consideration while analyzing the principal component analysis (PCA) scores for 45 groundnut genotypes in the initial three PCs were obtained, as well as the squared distance of each genotype from these axes

Table 1. Eigen values and percent variation contributed for the 10 PCs of 45 groundnut genotypes

Statistics	Eigen values	Expression of proportion of variance	Expression of cumulative proportion
PC 1	3.975	39.75	39.75
PC 2	2.213	22.13	61.88
PC 3	1.507	15.07	76.95
PC 4	0.918	9.18	86.13
PC 5	0.750	7.50	93.63
PC 6	0.581	5.81	99.44
PC 7	0.037	0.37	99.81
PC 8	0.014	0.14	99.95
PC 9	0.004	0.04	99.99
PC 10	0.001	0.01	100.00

Table 2. Factor loading of ten traits with respect to the significant of 45 groundnut genotypes

Statistics	PC1	PC2	PC3
Days to 50% flowering	0.1386	0.5304	-0.427
Days to maturity	0.1375	0.5272	-0.4133
Pods per plant	-0.4917	0.0725	-0.0928
Dry pod yield per plant (g)	-0.4923	0.0683	-0.1022
Shelling (%)	-0.1178	-0.3637	-0.2886
Solid mature kernel (%)	0.0556	-0.3283	-0.2144
100- kernel weight (g)	-0.0139	0.2689	0.3462
Biological yield per plant (g)	-0.466	0.192	0.1155
Biological yield per plant (g)	0.0204	-0.2857	-0.5881
Kernel yield per plant (g)	-0.4931	0.0045	-0.1393
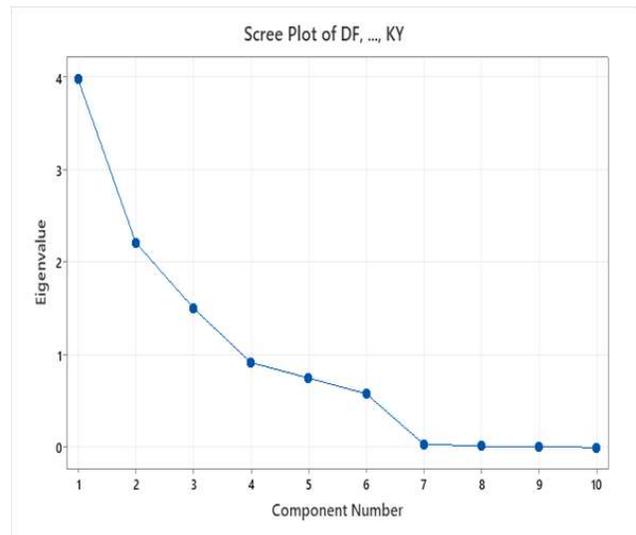
Fig. 1. Scree plot of 45 groundnut genotypes
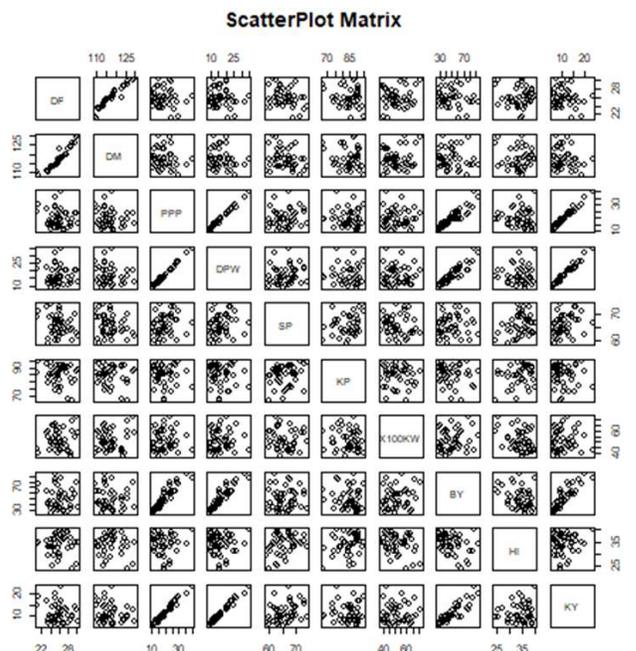
Fig. 2. Scatter plot with correlation value for ten traits of 45 groundnut genotypes

(Table 3). The best genotypes were those that were observed on the extreme positive side of both axes, such as RG 578 (2.74), RG 575-1 (2.38), RG 642-1 (1.70), RG 623 (1.29) along PCA I axis and genotypes RG 639 (2.79), RG 633-1 (2.69), RG 632 (1.75), RG 625 (1.68) along PCA II axis. These genotypes could be used in further hybridization development. The first two PCs are displayed in a biplot with trait loadings and the 45 groundnut genotypes dispersed throughout (Fig. 3). PCA clearly distinguished most of the
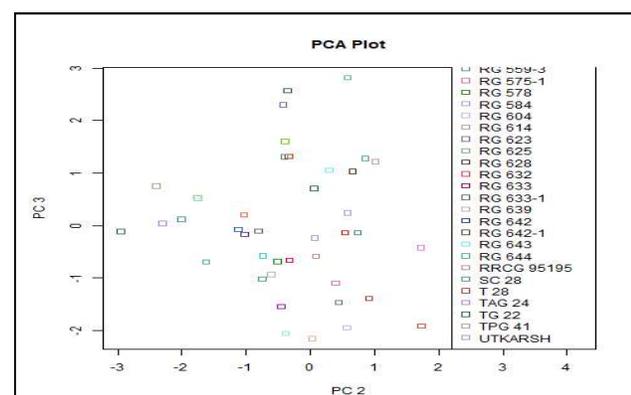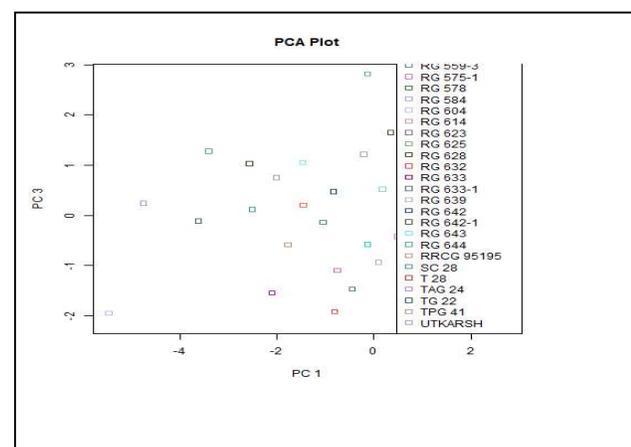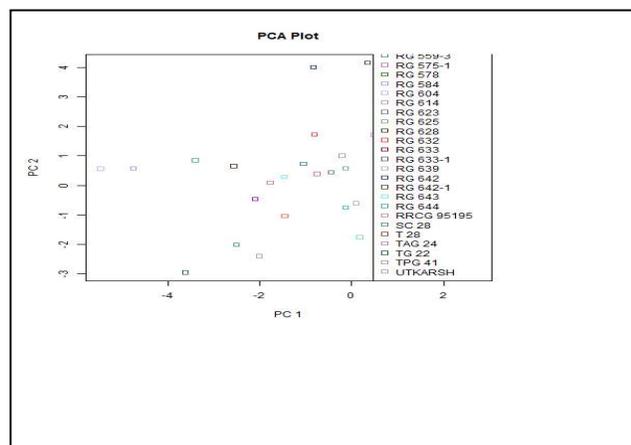
Fig. 3. Biplot of 45groundnut genotypesof PC I, PC II and PCIII

Table 3. PCA scores of 45 groundnut genotypes

Genotype	PC1 (X Vector)	PC2 (Y Vector)	PC3 (Z Vector)
CSMG 2003-19	-0.919	-0.228	-1.073
DGR 7	-0.491	-0.753	0.062
GG20	-0.244	1.156	0.347
GG21	-0.938	-0.269	-1.068
GIRNAR 2	-0.812	-0.348	0.559
HNG 10	-0.414	-1.095	0.569
HNG 69	-0.494	-0.267	-1.306
HNG 123	-1.252	0.039	-0.575
ICG 115-1	0.225	0.298	1.198
ICG 350	-1.368	0.042	0.196
ICG 3746	-0.807	-0.542	0.09
ICGV 6052	-1.242	-1.194	-0.443
ICGV 6119	-0.088	-1.179	-0.425
ICGV 86590	-1.302	-0.258	1.677
MH 1	0.066	-0.499	0.471
NRCG 12312	1.262	-1.353	-0.095
PUNJAB 1	-0.853	0.61	1.137
RG 382	-0.694	-0.24	-2.099
RG 420-1	1.01	-1.612	-0.613
RG 425	-0.472	-1.548	-0.034
RG 510	0.528	0.494	0.113
RG 559-3	0.381	0.265	0.893
RG 575-1	2.386	0.385	-0.198
RG 578	2.743	0.382	1.59
RG 584	0.109	0.679	-0.994
RG 604	-0.451	-0.284	-1.875
RG 614	0.069	0.391	-2.299
RG 623	1.29	0.442	-0.842
RG 625	0.41	1.162	1.562
RG 628	-1.176	1.686	1.116
RG 632	-0.31	1.754	0.177
RG 633	-0.047	-0.409	0.763
RG 633-1	0.422	2.69	-0.385
RG 639	-0.17	2.799	-1.343
RG 642	0.738	0.198	-0.86
RG 642-1	1.708	0.575	-1.043
RG 643	1.054	-0.307	1.26
RG 644	-0.269	-0.69	0.135
RRCG 95195	0.89	0.058	0.478
SC 28	0.73	-0.698	-0.169
T 28	1.82	-1.985	0.094
TAG 24	-0.522	-0.221	0.544
TG 22	-0.303	0.36	0.114
TPG 41	-1.168	-0.507	0.832
UTKARSH	-1.035	0.022	1.762

groundnut genotypes from each other. Similar results were observed by Sunday and Omolayo (2010).

CONCLUSION

The genotypes RG 578, RG 575-1, RG 642-1, RG 623, RG 639, RG 633-1, RG 632 and RG 625 had highest PC values for most important characters. Thus, these genotypes will may be used for advance hybridization programme.

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Analysis of Heterosis In Spring Maize (*Zea mays* L.) Germplasm to Heat Tolerance

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Abstract: This study evaluates 21 maize crosses through a series of 7x7 half diallel crosses initiated during the Rabi season in 2022 and planted again in the spring season of 2023 in Prayagraj, Uttar Pradesh. The objective was to assess mid-parent heterosis, heterobeltiosis, and economic heterosis based on the 20 characters analysed in maize. The mean sum of squares for all the characters suggested that parents were quite variable and a considerable amount of variability existed among the hybrids. Crosses P1xP7, P5xP6, P2xP6, P3xP5 and P1xP5 exhibited significant positive mid-parent heterosis values, whereas crosses P2xP6, P5xP6, P3xP5, P4xP5 and P1xP7 showed high heterobeltiosis values. Crosses P1xP7 and P2xP6 demonstrated significant positive economic heterosis. The hybrids P1xP7 and P2xP6 demonstrated superior performance in both yield and heat tolerance. The research provides valuable insights into developing maize cultivars resilient to heat stress crucial for enhancing agricultural sustainability in the face of challenges such as diminished yields, stunted growth and reduced productivity.

Keywords: Maize, Heterosis, Heat, Yield

Maize (*Zea mays* L.) commonly referred to as corn, is believed to have originated from central Mexico approximately 7000 years ago (Ranum et al 2014). Maize cultivation is preferred because of its easy-growing nature, ability to yield significant harvests, convenient storage options and high starch content which can be easily converted into usable energy. Spring maize is sown under low temperature conditions in the months of January and February, and the vegetative growth phase thus takes place at a range of low to medium temperatures in February and March. However, the reproductive stage of spring-sown maize occurs at high temperatures in May, and the crop is harvested under high temperature conditions in June and July. (Yousaf et al 2020). The reproductive stage of maize plants is extremely vulnerable to both suboptimal and excessively high temperatures. Departing from the optimal temperature range can trigger significant heat stress, leading to a notable decrease in growth rate and grain yield. This decline primarily stems from a reduction in the success rate of seed formation and disturbances in various physiological processes.

It is anticipated that by 2050, approximately 45% of the maize production regions worldwide are expected to experience, on average, five days each year during the reproductive stage with maximum temperatures exceeding 35ºC (Gourdji et al 2013). This is of significant concern because even a mere 1ºC increase in the average seasonal temperature has the potential to reduce the economic yield of maize by a substantial margin, ranging from 3% to 13% (Izzaurralde et al 2011). Elevated temperatures during critical stages of development can also negatively affect the quality of maize grains (Siebers et al 2017). Heat stress affects the integrity of the plasma membrane functioning of mitochondria and chloroplast, which further results in the over-accumulation of reactive oxygen species. The activation of a signal cascade subsequently induces the transcription of heat shock proteins. The denaturation and accumulation of misfolded or unfolded proteins generate cell toxicity, leading to death. Therefore, developing maize cultivars with significant heat tolerance is urgently required. (El-Sappah et al 2022). Tassel blast in maize is vital for successful pollination and grain yield, while monitoring leaf firing serves as an indicator of plant stress. The occurrence of tassel blast and leaf firing directly influences grain yield in maize, reflecting the intricate relationship between plant health and productivity.

The purpose of this study was to assess genetic parameters within a 7x7 half diallel cross and evaluate various forms of heterosis, including mid-parent heterosis, heterobeltiosis and economic heterosis, concerning grain yield in spring maize. Additionally, the research aimed to identify the superior heat tolerant germplasm among the maize genotypes under investigation.

MATERIAL AND METHODS

Experimental location: Prayagraj, SE Uttar Pradesh, India, features a subtropical climate with scorching summers (up to 48°C), chilly winters, 983 mm yearly rain (July-October), sandy loam soil, low organic carbon, nitrogen, phosphorus, and potash. The location coordinate is 25.409459° N latitude and 81.851543° E longitude.

Parental materials: The experiment involved seven parent maize lines, namely MILCT-2092 (P1), MILC-43 (P2), MILC-2093 (P3), MILC-2091/A (P4), MILV-1098 (P5), MILC-2050 (P6), and MILCT-145F (P7) which were sourced from the Directorate of Research, Sam Higginbottom University of Agriculture Technology and Sciences, Prayagraj. The research was conducted at Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Uttar Pradesh) during the spring of 2023.

Development of hybrids: In the previous *rabi* season of 2022, a set of experimental maize hybrids were developed using a 7x7 half diallel mating design. This resulted in a total of 21 maize hybrids, denoted as P1×P2, P1×P3, P1×P4, P1×P5, P1×P6, P1×P7, P2×P3, P2×P4, P2×P5, P2×P6, P2×P7, P3×P4, P3×P5, P3×P6, P3×P7, P4×P5, P4×P6, P4×P7, P5×P6, P5×P7 and P6×P7. These hybrids were generated through diallel mating involving seven carefully chosen parental genotypes during the Rabi season of 2022. The seeds of the 21 F1 hybrids, along with the initial seven parent lines and SHIATS Makka-3 (check), were gathered and stored in the Department of Genetics and Plant Breeding at Naini Agricultural Institute, Sam Higginbottom University of Agriculture Technology and Sciences, situated in Prayagraj, Uttar Pradesh. These seeds were subsequently stored and then cultivated once more during the scheduled spring season, which was from February to June in the year 2023.

Evaluation of experimental materials: During spring 2023, study was conducted in F1 maize populations, their seven parent plants and the check in an experimental field, with three replications. Plant characteristics were assessed, encompassing the timing of tassel and silk emergence, the duration between these events, tassel blast percentage, plant height, plant girth, leaf length and width, leaf firing extent, and days to maturity. Moreover, the chlorophyll content, indicative of plant health, was also examined. Following the harvest, measurements were collected for cob length, cob girth, cob weight, number of grain rows per cob, number of grains in each row, total grain count per cob, shank weight, seed index, and grain yield per plant. To gather this data, observations were made on five healthy maize plants within each replication, except for specific traits such as tassel and silk emergence, tassel blast, leaf firing and days to maturity, which were recorded for each plot.

Statistical analysis: The collected data were analysed using the statistical software TNAUSTAT (Nadarajan et al 2016), to estimate various genetic parameters. The software calculated three types of heterosis: mid-parent heterosis (MPH), heterobeltiosis (HB), and economic heterosis (EH). For the computation of standard heterosis, the high-yielding variety SHIATS Makka-3 was chosen as the standard check. Heterosis was assessed using three formulas: mid-parent heterosis (MPH), heterobeltiosis (HB), and economic heterosis (EH), which respectively measure the difference between F1 hybrid and parental means, the better parental mean, and a high-yielding standard check.

RESULTS AND DISCUSSION

Analysis of characters in maize: The mean sum of squares for all characteristics in the hybrid group showed significance (Table 1). Among the parent group, the mean sum of squares for all characteristics was significant, except for leaf width and days to maturity. When comparing the mean sum of squares between parents and hybrids, most characteristics exhibited statistical significance, except for chlorophyll content, number of grain rows per cob and seed index. These findings suggest that the parents displayed significant variability, and there was a substantial amount of diversity among the hybrids. Furthermore, the presence of heterosis was observed in most of the characteristics studied in the hybrids. Similar results were reported by Patil et al (2016) and Jebaraj et al (2023). The outcome indicated variations in the performances of the crosses, which were also compared to their respective parent plants. The level of diversity within the population is sufficient to facilitate the process of selection and the development of heterotic combinations by employing a diverse range of parent plants.

Mid-parent heterosis values of hybrid varieties: Among the twenty-one hybrids that were analysed for grain yield, the top five performing hybrids were P1xP7, P5xP6, P2xP6, P3xP5 and P1xP5 in decreasing order (Table 2). The best performing hybrids ranged in value from 66.78% in P7xP1 to 32.67% in P1xP5.

Heterobeltiosis values of hybrid varieties: The hybrids P2xP6, P5xP6, P3xP5, P4xP5, and P1xP7 displayed significant levels of heterobeltiosis for grain yield in decreasing order (Table 3). Particularly noteworthy, heterobeltiosis values were highly significant for genotypes P2xP6 and P5xP6. Values ranged from 44.98% in P2xP6 to 19.23% in P1xP7.

Economic heterosis values of hybrid varieties: Two hybrids, P1xP7 with 19.79% and P2xP6 with 18.5% outperformed the control variety SHIATS Makka-3 in terms of grain yield (Table 4). For traits such as days to 50% tasselling,

days to 50% silking, anthesis silking interval, days to maturity, plant height, leaf firing, and tassel blast, a significant number of the crosses that showed pronounced negative heterosis, held a dominant influence. On the contrary, for other traits like plant girth, leaf length, leaf width, cob length, cob girth, chlorophyll content, cob weight, number of grain rows per cob, number of grains per row, number of grains per cob, shank weight, seed index and grain yield per plant, the majority of the crosses displayed significant positive heterosis. This indicates that, in the case of these traits, genes with positive effects held dominance.

Heat tolerance of maize hybrids: The hybrid P2xP6 exhibited substantial negative mid-parent, heterobeltiosis and economic heterosis values for leaf firing, while the hybrid P1xP7 demonstrated similarly significant negative mid-parent and economic heterosis values for tassel blast. These findings suggest that these two genotypes P1x P7 and P2xP6 possess heat tolerance and high yielding potential. Upon comparing all three types of heterosis for both grain yield per plant and heat tolerance, genotypes P1xP7 and P2xP6 performed better than the other genotypes. Similar findings were reported by Dash et al (2020) and Talekar et al (2021). The significant positive value of heterosis suggests a wide genetic divergence between the parents. The presence of both significantly positive and significantly negative values of heterosis in specific hybrid combinations highlights variations in gene action attributed to the genetic makeup of the parents. This is of paramount importance for identifying superior crossbreeding combinations. The results reveal a connection between heterosis, grain yield, and heat tolerance in the studied hybrids. The hybrids displaying substantial heterosis demonstrate enhanced grain yield, particularly under heat stress conditions. This correlation highlights the potential synergy between heterosis and heat tolerance, suggesting avenues for developing resilient crop varieties to mitigate the impacts of climate change on agricultural productivity.

Table 1. Analysis of variance of characters in maize

Characters	Mean sum of squares					
	Replicates	Treatments	Parents	Hybrids	Parents Vs. Hybrids	Error
DF	[2]	[27]	[6]	[20]	[1]	[54]
D50T	0.3	13.17 **	28 **	7.88 **	30.04 **	2.32
D50S	0.58	13.13 **	29.21 **	7.43 **	30.73 **	2.36
ASI	0.32	0.53 **	0.49 **	0.50 **	1.29 **	0.25
TB	0.1	35.78 **	24.41 **	39.96 **	20.51 **	12.3
PH	64.99	1019.39 **	356.94 **	855.43 **	8273.20 **	527.42
PG	0.28	0.45 **	0.24 **	0.44 **	1.97 **	0.24
LL	17.7	142.64 **	119.54 **	114.31 **	847.73 **	71.68
LW	0.33	1.11 **	0.53	1.17 **	3.50 **	0.52
CC	0.77	5.69 **	8.88 **	4.99 **	0.61	2.7
LF	1.8	106.68 **	118.79 **	103.69 **	93.87 **	41.08
DM	0.11	6.44 **	3.22	3.95 **	75.57 **	3.1
CL	0.5	11.81 **	15.48 **	6.66 **	92.77 **	5.06
CG	0.27	1.89 **	1.58 *	1.94 **	2.65 *	0.96
CW	175.05	902.39 **	844.33 **	494.01 **	9418.45 **	352.8
NGRC	0.32	4.51 **	4.05 **	4.81 **	1.3	2.27
NGR	1.41	54.49 **	90.64 **	38.57 **	156.04 **	22.62
NGC	64.12	10369.31 **	14997.03 **	6985.14 **	50286.41 **	4114.73
SW	2.07	21.65 **	15.98 **	22.56 **	37.49 **	9.06
SI	4.26	6.05 **	10.53 **	5.00 **	0.18	3.41
GY	0.48	642.88 **	679.69 **	590.59 **	1467.89 **	268.79

* Significant at 5% and ** Significant at 1% respectively
D50T- Days to 50% Tasselling, D50S- Days to 50% silking, ASI-Anthesis silking interval, TB- Tassel blast, PH- Plant height, PG- Plant girth, LL- Leaf length, LW- Leaf width, CC- Chlorophyll content, LF- Leaf firing, DM- Days to maturity, CL- Cob length, CG- Cob girth, CW- Cob weight, NGRC- Number of grain rows per cob, NGR- Number of grains per row, NGC- Number of grains per cob, SW- Shank weight, SI- Seed index and GY- Grain yield per plant

Table 2. Mid-parent heterosis values of hybrid varieties

Genotype	P1xP7	P5xP6	P2xP6	P3xP5	P1xP5
D50T	-2.56	-2.59	-1.42	0.5	-2.13
D50S	-2.7	-2.73	-1.83	0.49	-2.52
ASI	-33.33**	-14.29	-17.65*	-20*	-20*
DM	-3.17**	-0.89	-2.65**	1.26	-1.42
LF	35.26**	15.48*	-26.33**	-17.19*	8.65
TB	-54.17**	33.93**	49.14**	2.82	2.82
PH	20.46**	20.11**	18.04*	8.26	14.71
PG	4.97	3.18	10.06*	14.75**	-0.76
LL	16.83**	11.53	12.68*	-0.05	1.57
LW	8.19	12.86*	32.6**	11.53*	13.13*
CL	44.64**	16.48*	40.72**	11.46	39.95**
CG	24.16**	13.07**	9.8*	0.79	13.48**
CC	-8.31**	-2.92	4.85*	-0.88	3.04
CW	72.7**	35.92**	62.61**	19.48*	51.38**
NGRC	13.67*	15.23**	3.49	-2.16	7.85
NGR	34.77**	33.56**	38.4**	14.78	43.46**
NGC	38.68**	26.81**	27.89**	18.32*	53.98**
SW	21.57*	13.13	37.11**	-11.76	50.79**
SI	17.54**	6.11	10.32	13.06*	8.42
GY	66.78**	52.64**	42.28**	36.49**	32.67*

* Significant at 5% and ** Significant at 1% respectively

Table 3. The value of heterobeltiosis of the hybrid varieties

Genotype	P2xP6	P5xP6	P3xP5	P4xP5	P1xP7
D50T	-5.02 **	-5.48 **	-2.91	-0.48	-3.69 *
D50S	-5.29 **	-5.73	-2.82	-0.47	-3.57 *
ASI	-22.22 *	-25.00 *	-33.33 **	-14.29	-33.33 **
DM	-2.82 **	-1.77	1.08	-4.58 **	-3.17 **
LF	-27.01**	8.04	-26.05 **	-47.01 **	30.00 **
TB	39.20 **	29.28 **	-2.45	-32.57 **	-56.22 **
PH	10.92	13.89	4.43	8.38	13.05
PG	8	1.49	11.99 *	10.9	1.73
LL	8.67	4.33	-7.18	23.99**	15.14*
LW	31.87**	6.97	3.48	3.98	4.81
CL	19.23*	15.16*	8.1	4.4	18.12*
CG	9.8	10.95*	-4.19	-5.07	20.87**
CC	4.85*	-3.37	-1.9	6.58**	-12.49**
CW	40.82**	35.61**	9.46	8.51	42.08**
NGRC	-11.10 **	11.67	-2.71	-11.90 **	8.81
NGR	28.46**	28.86**	10.01	9.24	1.83
NGC	25.83 **	16.58 *	11.2	19.16 **	5.83
SW	14.7	-2.51	-21.86 *	18.16	6.5
SI	6.92	0.56	12.94	-16.89 **	4.83
GY	44.98 **	42.63**	27.92*	23*	19.23*

* Significant at 5% and ** Significant at 1% respectively

Table 4. Economic heterosis values exhibited by high-performing hybrids

Genotype	P1xP7	P2xP6
D50T	-2.56*	-4.15*
D50S	-3.57*	-5.29**
ASI	-25*	-12.5
DM	-4.51**	-4.17**
LF	31.86**	-27.46**
TB	-19.87*	67.31**
PH	-2.37	-9.06
PG	-4.54	-2.11
LL	4.44	-8.1
LW	9.55	20.6**
CL	10.1	2.33
CG	4.27	2.39
CC	2.42	10.49**
CW	-5.46	-3.24
NGRC	-3.89	1.83
NGR	10.3	0.52
NGC	6.89	5.8
SW	-21.37**	-13.81*
SI	-2.17	-11.18*
GY	19.79*	18.5*

* Significant at 5% and ** Significant at 1% respectively
D50T- Days to 50% Tasselling, D50S- Days to 50% silking, ASI-Anthesis silking interval, DM- Days to maturity, LF- Leaf firing, TB- Tassel blast, PH- Pant height, PG- Plant girth, LL- Leaf length, LW- Leaf width, CL- Cob length, CG-Cob girth, CC-Chlorophyll content, CW- Cob weight, NGRC- Number of grain rows per cob, NGR- Number of grains per row, NGC- Number of grains per cob, SW- Shank weight, SI-Seed index and GY- Grain yield per plant

CONCLUSION

Based on all three forms of heterosis concerning both grain yield per plant and heat tolerance, genotypes P1xP7 and P2xP6 excelled in comparison to the other genotypes. The connection between heat tolerance and grain yield underscores the importance of breeding and selecting maize varieties that exhibit strong heat tolerance. By doing so, farmers can mitigate the negative effects of heat stress and achieve more consistent and higher grain yields, even in regions prone to heat waves and rising temperatures due to climate change. This interplay between heat tolerance and grain yield in maize is a key consideration for ensuring food security and sustainable agriculture in the face of changing environmental conditions.

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Population Dynamics of Predatory Phytoseiid Mite, *Neoseiulus longispinosus* (Evans) on Brinjal

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Abstract: The peak incidence of *N. longispinosus* was observed on brinjal during second fortnight of April 2018 i.e. during 17th (2.375 active stages/leaf) and 18th (2.318 active stages/leaf) standard meteorological week (SMW). The incidence of egg stage was found to range from 0.00 to 0.42 per leaf. Phytoseiid mite population showed a decreasing trend when temperature increased or decreased than 37.0 °C. Temperature range from 15.5 to 26.1°C (mid-October to end of February) was not found favourable for the development of *N. longispinosus* under natural conditions. The population of eggs and active stages of *N. longispinosus* was found to have a positive correlation with maximum temperature while it showed a negative correlation with minimum temperature. A negative correlation of rainy days was also observed with the population of eggs and active stages of *N. longispinosus*.

Keywords: Brinjal, Predatory mite, *Neoseiulus longispinosus*, Population dynamics, Weather parameters

The phytophagous mites are key pests of many agricultural crops. Phytophagy in Acari is seen in families Tetranychidae, Tenuipalpidae, Tarsonemidae, Eriophyidae and Tuckerellidae. Mites were considered as minor pests of agricultural crops, but in present scenario they have become major pest due to the repeated use of synthetic pesticides and elimination of natural enemies (Hoy 2011, Dhooria 2016). Tetranychidae is a moderately large family comprising of more than 1200 described species (Krantz and Walter 2009). For the management of mite pests especially the polyphagous two-spotted spider mite *Tetranychus urticae* Koch, several new molecules of acaricides have been introduced. The repeated and injudicious use of these chemicals led to the development of acaricidal resistance in mites in different crops, mainly due to the shorter developmental period and higher fecundity of these mite pests (Leeuwen et al 2010). The development of resistance is proving to be a great obstacle in the effective integrated mite management programmes. In Punjab, higher levels of resistance in two-spotted spider mite, *Tetranychus urticae* Koch were detected for dicofol (195-fold) (Kaur and Bhullar 2011), propargite and spiromesifen (Kaur and Bhullar 2016) and fenazaquin (Sharma and Bhullar 2018). Therefore, there is a need to explore biocontrol agents for the suppression of the two-spotted spider mite population. There are many natural enemies of mites like predatory insects *viz.* coccinellid, *Stethorus* sp., *Oligota* sp., and predaceous mites which have been proven to be voracious feeders of phytophagous mites. Among the acarine mite predators,

predatory mites belonging to family Phtyoseiidae mites are most promising, as they have shorter life cycle than other group of predators and they can also be mass produced fairly easily.

More than 2280 species of phytoseiids have been reported from world by Chant and McMurtry (2007) and many new species have been described since then as per the Phytoseiidae world database. From India 169 species were reported by Gupta (1985) which have been raised to 247 through the contribution of several workers (Gowda 2009, Karmakar and Gupta 2011, 2015, Bhowmik and Karmakar 2021). From Punjab, 13 species of phytoseiid mites were reported by Biswas et al (2022). Many species of family Phytoseiidae have been exploited for suppression of phytophagous mites and amongst them the species, *Neoseiulus longispinosus* (Evans) has been reported as a potential biocontrol agent against several spider mites. *N. longispinosus* was first described from Indonesia as *Amblyseius longispinosus* (Evans 1952) and is widely distributed in Taiwan, Philippines, Indonesia, India, Australia, China, Thailand, Malaysia, Pakistan, Papua New Guinea, Hawaii and New Zealand (Ho et al 1995, Ehara 2002a, 2002b). In India, it has been found as a widely distributed species and observed to feed on tetranychids on different crops (Karmakar and Gupta 2011, Haneef and Sadanandan 2013, Biswas et al 2022). Few studies on exploration of this species as biological control agent have been done in Punjab, India (Nag et al 2020, Bhullar et al 2021). But negligible studies are available pertaining to the natural

occurrence of this mite on brinjal. Therefore, the present study was planned to study the population dynamics or the seasonal incidence of phytoseiid predatory mite, *N. longispinosus* on brinjal.

MATERIAL AND METHODS

Brinjal, variety *Punjab Sada Bahar,* was raised at Entomological Research Farm, Punjab Agricultural University, Ludhiana as per the recommended Package of Practices for cultivation of Vegetable crops. Four crops of brinjal were transplanted in different seasons viz. first crop in 2nd fortnight of February (17.02.2017), second in 2nd fortnight of April (28.04.2017), third in 2nd fortnight of August (28.08.2017) and fourth in 2nd fortnight of November (28.11.2017). The population dynamics of *N. longispinosus* was studied throughout the year. The weekly observations on mite population were started after 45 days of transplanting. For recording the incidence or population of *N. longispinosus*, three leaves each from top, middle and bottom canopy were taken from ten randomly selected plants. The leaf samples were brought to the laboratory and observed under Magnus stereo zoom binocular microscope. The number of eggs and active stages of *N. longispinosus* were recorded separately. Maximum and minimum temperature, relative humidity, rainfall and rainy days were also recorded during the crop season at Ludhiana. Correlation analysis was worked out with the mite population and standard meteorological week (SMW) weather data. Partial correlations were worked out between mite population and weather parameters by using the SPSS software. Results were analysed at 1 and 5 per cent levels of significance.

RESULTS AND DISCUSSION

Population dynamics of *N. longispinosus* on brinjal: The population of *N. longispinosus* was observed on brinjal throughout the crop season. The population started increasing in 12th and 13th (0.718 active stages/leaf) SMW (end of March), and showed peak incidence in April end in 2018 i.e. during 17th (2.375 active stages/leaf) and 18th (2.318 active stages/leaf) SMW, which further showed a decreasing trend in mid of May i.e. 19th (0.542 active stages/leaf) SMW. However, population of eggs during this period was in range of 0.00 to 0.419 per leaf. Population of *N. longispinosus* was maximum when the maximum temperature was recorded as 37.0°C. Population of mites decreased when temperature was observed to be less than or exceeded than 37.0°C. Thus, this temperature can be considered as optimum temperature for the growth of *N. longispinosus.* No population of *N. longispinosus* was found after mid-October to end of

February, when temperature was in the range of 15.5 to 26.1°C (Table 1). Population of eggs and active stages of *N. longispinosus* was comparatively more in February and April grown crop as compared to August and November grown crop of brinjal (Table 2).

Partial correlation coefficients between mite populations and abiotic factors: The partial correlation coefficients between the abundance of predatory mite, *N. longispinosus* with the abiotic factors i.e. maximum and minimum temperature, maximum and minimum relative humidity, rainy days and precipitation (mm) was worked out. The population of egg and active stages of *N. longispinosus* was found positively correlated with maximum temperature and negatively correlated with minimum temperature, but the correlations were non-significant. The morning relative humidity showed a negative correlation with the population of eggs and active stages whereas, the evening relative humidity showed positive correlation with both the egg and active stages. Effect of rainy days was also negatively correlated with the population of active stages of *N. longispinosus* (Table 3).

Rachana et al (2009) recorded the population of *N. longispinosus* on *Tetranychus neocaledonicus* (André) in Shimoga region of Karnataka. Rajgopal and Srinivasa (2017) also reported greater predaceous activity of *N. longispinosus* during the summer season against *Tetranychus macfarlanei* (Baker and Pritchard) on okra. Rinkikumari *et al* (2017 recorded 0.13 mites per leaf during the 2nd SMW and reported gradual increase in population during 22nd SMW (last week of May) with 5.40 predatory mites/ leaf. Singh and Chauhan (2018) in Himachal Pradesh under polyhouse conditions recorded 8 species of predatory mites *viz. Euseius prasadi* (Chant & McMurty), *E. finlandicus* (Oudemans), *E. delhiensis* (Narayanan & Kaur), *E. alstoniae* (Gupta), *N. paspalivorus* (DeLeon), *N. longispinosus*, *P. roseus* (Gupta) and *Lasioseius sp*. and   *E. prasadi* was dominant. Jasmine et al (2008) observed that that the predatory mite, *N. longispinosus* had positive correlation with the eggs and active stages of its prey i.e. *T. macferlanei* and *Oligonychus indicus* (Hirst) as well as with average temperature and average relative humidity. Singh and Singh (2014) recorded the seasonal incidence of *T. neocaledonicus* and *N. longispinosus* on brinjal and observed a significant positive correlation with maximum temperature, whereas negative correlation with minimum temperature, relative humidity and rainfall was observed. Shah (2014) reported that the incidence of predatory mite, *N. longispinosus* had significant positive correlation mean temperature while significant negative correlation existed with mean relative humidity. There was significantly positive relationship of population of *N. longispinosus* and *T. urticae* with maximum

Table 1. Population of phytoseiid predatory mite, *N. longispinosus* on brinjal and weather parameters

SMW	Mean population/leaf		Temperature (°C)		Relative humidity (%)		Rainfall	
	Eggs	Active stages	Maximum	Minimum	Morning	Evening	Precipitation (mm)	Rainy days
1	0.000	0.000	15.9	5.4	96.0	66.0	0.0	0.0
2	0.000	0.000	20.8	5.3	94.0	43.0	0.0	0.0
3	0.000	0.000	22.0	6.1	92.0	40.0	0.0	0.0
4	0.000	0.000	15.5	7.6	93.0	76.0	18.4	1.0
5	0.000	0.000	21.2	7.6	91.0	46.0	0.0	0.0
6	0.000	0.000	21.1	5.6	89.0	38.0	2.4	0.0
7	0.000	0.000	21.1	9.3	89.0	53.0	21.4	1.0
8	0.011	0.000	25.5	11.7	88.0	48.0	3.2	0.0
9	0.011	0.000	25.8	13.1	89.0	51.0	0.0	0.0
10	0.154	0.220	27.2	12.2	88.0	42.0	0.0	0.0
11	0.088	0.242	29.9	14.1	85.0	30.0	0.0	0.0
12	0.286	0.705	29.2	14.2	86.0	44.0	0.0	0.0
13	0.321	0.718	33.1	16.5	74.0	29.0	0.0	0.0
14	0.264	0.353	34.8	20.3	69.0	33.0	0.0	0.0
15	0.000	0.090	36.6	15.1	56.0	13.0	0.0	0.0
16	0.011	0.676	41.7	23.6	51.0	23.0	0.0	0.0
17	0.000	2.375	36.9	21.5	54.0	23.0	8.6	1.0
18	0.011	2.318	37.0	22.2	46.0	22.0	0.0	0.0
19	0.354	0.542	40.9	26.1	48.0	21.0	0.0	0.0
20	0.110	0.154	39.2	25.7	50.0	24.0	0.0	0.0
21	0.419	0.132	39.0	26.4	51.0	32.0	10.0	1.0
22	0.264	0.055	37.5	24.5	59.0	34.0	21.6	1.0
23	0.110	0.088	38.9	27.3	58.0	35.0	26.6	1.0
24	0.022	0.054	38.5	25.9	53.0	30.0	5.0	1.0
25	0.022	0.055	34.5	25.5	75.0	53.0	18.8	2.0
26	0.033	0.088	33.7	27.7	75.0	61.0	77.2	3.0
27	0.066	0.165	35.4	25.7	80.0	59.0	39.6	4.0
28	0.055	0.143	35.1	28.3	74.0	59.0	9.8	2.0
29	0.022	0.032	34.5	28.5	79.0	61.0	25.0	1.0
30	0.110	0.012	34.1	27.7	79.0	62.0	37.4	1.0
31	0.000	0.022	32.6	27.2	85.0	72.0	20.6	2.0
32	0.011	0.033	35.0	28.0	82.0	66.0	0.0	0.0
33	0.000	0.044	35.0	27.6	80.0	61.0	15.0	1.0
34	0.000	0.033	33.3	25.8	85.0	65.0	11.6	1.0
35	0.000	0.033	32.0	25.7	84.0	74.0	100.0	3.0
36	0.000	0.044	33.7	24.7	81.0	61.0	24.0	1.0
37	0.000	0.022	33.9	24.5	85.0	55.0	0.0	0.0
38	0.000	0.022	33.9	23.1	85.0	49.0	7.4	1.0
39	0.022	0.033	34.6	23.3	88.0	49.0	0.0	0.0
40	0.000	0.011	34.9	21.0	85.7	37.7	0.0	0.0
41	0.000	0.022	34.4	21.1	91.0	43.0	0.0	0.0
42	0.000	0.000	34.3	17.3	90.0	32.0	0.0	0.0
43	0.000	0.000	31.3	16.2	87.0	36.0	0.0	0.0
44	0.000	0.033	28.0	15.3	91.0	53.0	0.0	0.0
45	0.000	0.000	26.1	14.1	96.0	57.0	0.0	0.0
46	0.000	0.000	22.3	12.9	90.0	60.0	7.0	1.0
47	0.000	0.000	23.9	7.4	94.0	29.0	0.0	0.0
48	0.000	0.000	25.4	7.9	94.0	31.0	0.0	0.0
49	0.000	0.000	22.7	7.3	87.0	30.0	0.0	0.0
50	0.000	0.000	17.1	9.3	90.0	70.0	24.0	1.0
51	0.000	0.000	21.9	7.4	91.0	47.0	0.0	0.0
52	0.000	0.000	20.7	6.3	96.0	49.0	0.0	0.0

Table 2. Population of phytoseiid predatory mite, *N. longispinosus* in different seasons on brinjal

Life stage	April-July	August-October	February-April	November-January
		Mean population/leaf		
Egg	0.100	0.002	0.110	0.000
Active stages	0.430	0.024	0.540	0.001

Table 3. Partial correlation coefficients between mite population and abiotic factor on brinjal

Life stage	Temperature (°C)		Relative humidity (%)		Rainfall	
	Maximum	Minimum	Morning	Evening	Rainy days	Precipitation (mm)
Egg	0.191	-0.195	-0.172	0.096	0.001	-0.020
Active stages	0.264	-0.258	-0.218	0.167	-0.011	0.033

and minimum temperature (Rinkikumari et al 2017). Rao et al (2018) reported that maximum temperature and minimum temperature had positive relationship with the incidence of *T. urticae* and *N. longispinosus*. Thus, the difference in results in the present findings might be due to the crop and growing conditions.

CONCLUSION

The population of *N. longispinosus* was observed on brinjal throughout the crop season with maximum incidence during end of April at a temperature of 37.0°C. The phytoseiid mite population decreased when temperature was more or less than 37.0 °C. Thus, this temperature can be considered as optimum temperature for the growth of *N. longispinosus.* Temperature in the range of 15.5 to 26.1°C (mid-October to end of February) was not favourable for the development of *N. longispinosus* as no mites were observed in this period. Population of *N. longispinosus* was comparatively more in February and April grown crop. The abiotic factors *viz*., maximum temperature and evening relative humidity had positive correlation while morning relative humidity had negative correlation with the population of *N. Longispinosus* on brinjal.

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Synomonal and Kairomonal Mediated Tritrophic Interactions between Brinjal Cultivars, Mealybug *Coccidohystrix insolita* Green and Natural Enemy *Chrysoperla zastrowi sillemi* Esben-Peterson

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Abstract: The orientation response of *Chrysoperla zastrowi sillemi* Esben-Peterson adults towards the synomonal compounds of different mealybug infested brinjal cultivars were evaluated using a multi-armed olfactometer and the results revealed that the cultivar Udit attracted the highest number of natural enemies while the cultivar Pusa Uttam attracted the lowest number. The differences in compounds and their concentration in the volatile profile of the cultivars may lead to the highest preference of *C. zastrowii sillemi* to Udit and the lowest preference to Pusa Uttam. The relative response of *C. zastrowi sillemi* adults to the synomonal extracts of healthy and mealybug infested brinjal cultivars in a Y- tube olfactometer were evaluated and the results revealed that *C. zastrowi sillemi* adults showed more preference towards the synomonal compounds of mealybug infested plants than that of healthy synomonal extracts. The relative response of *C. zastrowi sillemi* towards the kairomonal compounds of mealybug *Coccidohystrix insolita* Green was also evaluated in a Y tube olfactometer and the results revealed that the highest mean number of adult lacewings were attracted to the kairomonal compounds of mealybug compared to control n-hexane. The present study revealed that the difference in composition of hydrocarbons in volatile blend determined the selectivity of natural enemy, *C. zastrowii sillemi*.

Keywords: Infochemicals, Olfactometer, Volatile hydrocarbons, Brinjal cultivars, Orientation response, Semio-chemicals, Intra specific communication, Ecosystem

Info-chemicals are involved in intraspecific and interspecific communication, and the latter plays a vital role in maintaining tritrophic interactions. The info-chemical mediated tritrophic interactions in the ecosystem mainly operates through allelochemicals which include allomones, kairomones and synomones (Arimura et al 2009). When plants are infested by herbivores, they emit plant volatiles that serve as signals to natural enemies, indicating the presence of herbivores. This communication benefits the plant by attracting the natural enemies of pests, while also assisting the natural enemies in locating suitable host organisms (Sheikh et al 2017). Tritrophic interactions within an ecosystem can exhibit varying dynamics based on the host plant species or the genotypes present within those host plants (Valencia-Cuevas et al 2018). The herbivorous insects are able to discriminate its host and non-host plants and even they can distinguish their host plants of different quality. The conspecific and hetero-specific interactions in an ecosystem coupled with environmental factors may modify the host searching capability of insects by altering the quality of host (Ninkovic et al 2019). Similarly, the carnivorous insects are responding to the volatile cues emanated from the plants infested with their prey and are able to distinguish the cues emanated from mechanically damaged plants and insect infested plants (Yoon et al 2010). The difference in the volatile blend of these synomones recruit specific natural enemies to the host plant. Likewise, the kairomonal compounds emanated from the prey species also act as a volatile cue for guiding natural enemies to the target pest (Turlings and Erb 2018).

The brinjal mealybug, *Coccidohystrix insolita* Green is prevalent in the Indian subcontinent and even distributed in other parts of the oriental region, Afro-tropical and Palearctic region (Ben- Dov 2013). The management of mealybug is a difficult task due to the polyphagous nature, wide distribution, cryptic habitat and resistance development to pesticides. However, mealybugs are confronted by a diverse array of natural enemies that play a vital role in the regulation of the pest population. Worldwide, there have been documented about 118 species of predators and 79 species of parasitoids associated with mealybugs. Specifically within Kerala, 20 species of predators and 11 species of parasitoids have been recorded (Shylesha and Mani 2016, Mohan and Anitha 2023). So there is utmost importance in understanding the different species interactions in the ecosystem for developing a sustainable pest management strategy. The understanding of various levels of interactions that take place in between different trophic levels can lead to the development of

biological control methods that will not only yield fruitful results in pest suppression but also encourage the abundance and effectiveness of the entomophagous insect guild in natural as well as man-made ecosystems. So in this study, the relative response of the natural enemy *Chrysoperla zastrowi sillemi* Esben-Peterson towards the synomonal compounds of different brinjal cultivars infested by mealybug *C. insolita* was evaluated. The relative response of natural enemies towards infested and un-infested plant synomonal compounds and its response to mealybug kairomonal compounds were also tested.

MATERIAL AND METHODS

The experiments was conducted at Department of Agricultural Entomology, College of Agriculture, Vellayani, Trivandrum (N 8^{0}25'46.6788", E 76^0 59'15.02016") during the year 2019-2020. The laboratory experiments were conducted at a temperature of 27 ^{0}C and relative humidity of 65-70 %.

Extraction of Synomones

Un-infested brinjal cultivars: Ten cultivars of brinjal were maintained in insect -proof nylon cage separately inside the net house. The synomonal compounds were extracted from healthy leaf samples. Leaf sample (10g) was taken from each plant and immersed overnight in 100 mL of HPLC grade distilled hexane in glass bottles. The hexane extract was filtered through a Whatman No. 1 filter paper and anhydrous sodium sulphate (1g) was added and kept for 2h for dehydration. The hexane extract was subjected to column chromatography and was passed through the silica gel of 60 to 120 mesh size. The eluted compound was collected and distilled at a temperature of 60 to 70^{0}C in a rotary vacuum flash evaporator. The leftover residue was collected by rinsing the flask with HPLC grade hexane in a small glass vial. The compounds were stored at $^-$80 ^{0}C in a low-temperature cabinet (Trang 2008).

Infested with the mealybug *C. insolita*: Ten cultivars of brinjal were maintained under an insect-proof nylon cage in a net house. Twenty adult mealybugs were carefully inoculated into each plant using a soft camel brush at one month after transplanting. Twenty days after inoculation, the synomonal compounds were extracted from the mealybug infested leaf samples as per the procedure mentioned for extraction of synomonal compounds from un-infested brinjal cultivar.

Maintenance of natural enemy culture: A nucleus culture (eggs) of the predator, *C. zastrowi sillemi* was purchased from NBAIR, Bangalore and reared in the laboratory. The eggs (100 nos) were mixed with 0.75 cc of sterilized eggs of *Corcyra cephalonica* Stainton in a plastic container. The emerged larvae were transferred separately in to small plastic boxes and reared on the diet containing eggs of *C. cephalonica*. Brown paper was provided for facilitating cocoon formation in the plastic boxes. The cocoons were collected and placed in a glass jar for adult emergence. The emerged adults were maintained with a diet containing 50 % honey and castor pollen. The adult chrysopids were used for further studies.

Response of *C. zastrowi* sillemi to synomonal compounds of brinjal: The response of the natural enemy, *C. zastrowi sillemi* towards synomonal compounds of brinjal was evaluated by multi-armed olfactometer bioassay and Y tube olfactometer bioassay

Multi-armed olfactometer assay: Relative response of the predator *C. zastrowi sillemi* towards the synomonal compounds of various brinjal cultivars was evaluated in a multi-armed olfactometer. The olfactometer made up of glass with a central portion of 15 cm diameter and arm length of 10 cm and diameter of 2.5 cm was used for the study. The olfactometer was kept at a temperature of 27 ^{0}C and relative humidity of 65-70 % under a 40 W fluorescent lamp. The average airflow through each arm was maintained at 10 L/h. Synomonal compounds (50 µl) of each brinjal cultivar was taken in a Whatman filter paper of size 2 cm * 1 cm and placed in different arms of the olfactometer. N-hexane (0.5 mL) in a similar strip of filter paper was considered as control and placed in the remaining arm. Ten freshly emerged adult chrysopids were released at the central arena of the olfactometer and observed the response of the chrysopids at every 5 minutes for a period of 30 minutes. The experiment was repeated ten times and data regarding the relative preference of chrysopids towards synomonal extracts were recorded and analyzed.

Y-tube olfactometer assay: Based on the previous experiment, the most preferred and the least preferred brinjal cultivar to *C. zastrowi sillemi* were selected for a Y-tube olfactometer assay. The Y-tube olfactometer was made up of glass with 28 cm base length and arm length of 13 cm with 2.5 cm diameter. The olfactometer was kept at a temperature of 27^{0}C and relative humidity of 65 to 70 % under a 40 W fluorescent lamp. The synomonal extracts of mealybug infested and un-infested plants were tested to find out the relative response of *C. zastrowii sillemi* to the volatiles emanated from the plants. Synomonal extracts (50 µl each) were taken in separate filter paper bits and placed inside the two arms of the olfactometer. The individual adult chrysopids was released at one end of the base tube and given 4 minutes to walk towards the end of the olfactometer arm. The choice made by the chrysopids was recorded as it crossed about 4 cm in an olfactometer arm after the division of the base tube and remained for about 20 second in the odor source. After

testing 5 chrysopids, the olfactometer was washed with ethanol, rinsed using distilled water and dried in a hot air oven and the positions of odor sources were exchanged to avoid any bias in the experiment. The experiment was repeated with another 5 chrysopids and altogether considered as a single replication. The olfactometer assay was replicated 10 times.

Extraction of kairomones from *C. insolita*: The kairomonal compounds emanated from the mealybug body was extracted by immersing mealybug (1g) in 10 mL of HPLC grade hexane. The hexane extract was placed in a shaking water bath at a temperature of 28 ^{o}C for 2 h and later at a temperature of 50 ^{o}C for 20 minutes. The hexane extract was filtered through a Whatman No. 1 filter paper and passed through a silica gel column of 60 to 120 mesh size. The eluted compounds were distilled at 60 to70 ^{o}C in a rotary vacuum flash evaporator and the leftover residue was collected by rinsing the flask with HPLC grade hexane into a small glass vial. The compound was stored at $^{-}$80 ^{o}C in a low-temperature cabinet (Trang 2008).

Response of *C. zastrowi* sillemi to kairomonal compounds of *C. insolita*: The response of *C. zastrowii sillemi* adults towards the kairomonal compounds of *C. insolita* was evaluated in a Y-tube olfactometer. The olfactometer was kept at a temperature of 27 ^{o}C and relative humidity of 65 to 70 % under a 40 W fluorescent lamp. The kairomonal compound (50µl) was taken in a Whatman filter paper bit of size 2 cm * 1 cm and placed in one arm while n-hexane was taken as the control in another arm of the olfactometer. The experiment was conducted as per the procedure mentioned in Y tube olfactometer bioassay.

Statistical analysis: The data was analyzed by paired t-test and anova using GRAPE software.

RESULTS AND DISCUSSION

The multi armed olfactometer experiment to identify the relative preference of natural enemy *C. zastrowi sillemi*, to the synomonal compounds of different brinjal cultivars revealed that the cultivar Udit attracted the highest number of natural enemies (2.87) which was statistically superior to all other treatments (Table 1). However, significantly lowest number of *C. zastrowi sillemi* were oriented towards the cultivar, Pusa Uttam (0.28). The variation in preference shown by the natural enemies may be related to the difference in volatile compounds emanating from the host cultivar. Hanumantharaya (2006) conducted a six-armed olfactometer study to evaluate the response of the predator, *C. carnea* towards the synomonal extracts of cotton and sunflower genotypes revealed that the preference shown by the predator towards the cultivar DHH-543 and KBSH-1 was

due to the difference in the volatile profile of the cultivars. Similarly, Trang (2008) also reported that the parasitoid *Apanteles angaleti* Mues exhibited a higher preference towards the synomonal compounds of cotton genotype RS 2013 in a six-armed olfactometer study as the volatile profile of the cultivar made it more attractive to the parasitoid compared to other genotypes. Kumar et al. (2017) observed that synomones of the sugarcane cultivar, CO- 0238 attracted the highest number of parasitoid, *Cotesia* sp. and they suggested that the long-range cues emanating from the infested host plants played a significant role in guiding the parasitoids to the host plant.

The relative preference of natural enemy to *C. zastrowi sillemi* adults towards infested and healthy brinjal synomonal compounds were evaluated in a Y shaped olfactometer . *C. zastrowi sillemi* showed more preference towards the synomonal compounds of mealybug infested plants (5.20) than that of healthy synomonal extracts (2.90). The relatively high preference of natural enemies towards mealybug infested plant synomonal extracts may due to the presence of more volatile compounds in it compared to the healthy plant synomones. As a result of insect herbivory, a cascade of events take place in the plants which ultimately led to the higher production of plant volatiles that act as a reliable long-distance cue for natural enemies. The present findings are in consonance with Manna et al (2024). Jagdish (2008) and Xiu et al (2019) also demonstrated that coccinellid predators showed a higher preference towards the aphid infested plant synomonal compounds compared to healthy plant odors. Ahmed et al (2021) observed that aphid infested broccoli plants emitted a higher concentration of volatile organic carbons than un-infested plants. The variation in the volatile profile of healthy and mealybug infested plants may lead to the differential response of natural enemies to the synomonal compounds.

Table 1. Response of *Chrysoperla zastrowi sillemi* to synomonal compounds of brinjal cultivars

Cultivars	Number of *C. zastrowii* attracted
Haritha	2.26
Neelima	0.47
Ponni	0.83
Pink Long	0.67
Udit	2.87
Green Long	0.47
Pusa Purple Long	0.45
Pusa Kaushal	0.53
Pusa Uttam	0.28
Pusa Shyamla	0.42
n-hexane	0.38
CD (p=0.05)	0.24

Table 2. Response of *Chrysoperla zastrowi sillemi* towards synomonal compounds of healthy and mealy bug infested brinjal cultivar and kairomonal compounds of *Coccidohystrix insolita*

Treatments	Synomones from healthy plants	Synomones from mealybug infested plants	Kairomones from mealybug, *C. insoilta*	n-hexane (control)
Mean	2.90	5.20	5.90	2.80
Standard deviation	0.876	1.135	1.101	1.033
t test value (0.01)	3.25**		3.25**	

The highest mean number of adult lacewings were attracted to the arm containing kairomonal compounds of mealybug (5.90) compared to the arm containing n-hexane (2.80) in tube olfactometer study (Table 2). The higher preference of natural enemies towards the kairomonal compounds may be due to the volatiles present in it which act as olfactory cue for natural enemies. Urbina et al (2018) recorded that *Cryptolaemus montrouzieri* (Mulsant) exhibited significant response to the kairomones produced by different mealybugs. Fand et al. (2020) observed that the bacterial volatiles of the mealybug honeydew acts as a kairomone source to the parasitoid *Anagyrus dactylopii* (Howard).

CONCLUSION

The variation in preference shown by the *C. zastrowii sillemi* towards different brinjal cultivars may be related to the difference in volatile compounds emanating from the cultivar. Particularly, *C. zastrowii sillemi* exhibited more preference towards mealybug infested plant synomonal compounds rather than un-infested plants. The variation in the volatile profile of healthy and mealybug infested plants may lead to the differential response of natural enemies to the synomonal compounds. Likewise, mealybug kairomones attracted more *C. zastrowii sillemi* than the n hexane (control) which may be also due to the variation of hydrocarbon profile of the kairomones emanated from the mealybug.

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Efficiency of Food Bait Attractants and Volatile Compounds for Monitoring of Pests in Stored Paddy

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Abstract: Food baits are one of the ways for monitoring and mass trapping of stored product insects. Based on this principle wheat flour, sorghum flour, pearl millet flour, rice flour, cracked corn, crushed groundnut, rice bran + rice flour as attractive materials. Observations were taken on 25 days after placement of bait traps. Behavioural response of insects to wheat flour, cracked sorghum and pearl millet flour were more attractive. The effective baits were also test verified through four-arm olfactometer and found the highest orientation in the arm containing wheat flour. The major attractive volatile compounds present in the baits were analysed using GCMS/MS. The attractive volatile compounds such as 1- butanol, 3-octen-1-ol, pentanal, nonane and undecane were present in wheat. Butyric acid, 3-hexanal and 7-octen-4-one present in sorghum. Undecane 7-octen-4-one, 1-octanal, hexanal, butanal, nonanal present in pearl millet. The attractant compound 3-hexanal was present in groundnut and rice bran. Butanal and 7-octen-4-one were present in corn and rice bran respectively, attracted less insects. Volatile compounds such as pentadecanoic acid, n-Hexadecanoic acid, cis-Vaccenic acid and propionic acid acted as repellents. cis-vaccenic acid present in rice bran, effected low attraction. Therefore, the effective bait of wheat flour may be exploited for monitoring and trapping of insects in paddy storage godowns.

Keywords: Bait traps, Rice godown, Stored product insects, Volatile, Food bait attractants

Rice is one of the most important food crops for more than half of the world's population. Large number of people affected by food availability due to losses in storage rice. In storage godown, number of biotic and abiotic agents like insects, birds, mites, fungi, rodents and moisture are causing damage to rice (Pandey 2018). Storage insects cause more considerable losses in every year. Stored product insect particularly adult beetles due to their harbourage seeking behaviour seek refuge in cracks and crevices of warehouse and storage godown. Although it is very difficult to detect the activity of insects visually in storage godown, detection of insect population using bait trap with pheromones or food sources or combination of both pheromone and food attractants may influence in stored product insect management.

The food bait trap is one of the detection techniques for stored-product insects in storage (Neethirajan et al 2007). Olfactory cues play an important role as attractants, and diversity of substances are as kairomone for stored product pests (Rizana and Phillips 2007). The granary weevil, *Sitophilus granarius* is the most widely studied storage insect species with regard to its response to kairomone, with its reaction to crushed seed or whole seed (Reidorf and Steidle 2002). The present study aims at to know the response of insects to different host odours in paddy storage godowns.

The main objective of the study was to identify an easily available, cheap and effectively attracting bait source for major pests in stored paddy. Volatile chemical olfactory cues play an important role as attractants, and diversity of substances as kairomones for stored product pests (Rizana and Phillips 2007). The granary weevil, *Sitophilus granarius* is the most widely studied storage insect species concerning its response to kairomone, with its reaction to crushed seed or whole seed (Rietdorf and Steidle 2002). Since a lot of insect species feed on any one of the foods, volatile from this food attracts more than one species (Collins et al 2007). Combining food and pheromone odour can increase the pitfall traps efficiency against Sitophilus spp. (Likhayo and Hodges 2000, Wakefield et al 2005).

Bait traps have become the most useful tools in the management programmes of Angoumois grain moth, *Sitotroga cerealella*, lesser grain borer, *R. dominica*, red flour beetle, *Tribolium* spp. rice weevil, *S. oryzae* and saw-toothed grain beetle, *O. surinamensis*. Response of insects to various food bait attractants are wanting for efficient utilization of foods for the control of insects in paddy storage godown. Therefore the present study aims at to investigated the olfactory responses of insects by experimenting with different bait based materials in paddy storage godowns.

MATERIAL AND METHODS

Rearing of test insects: In plastic jar adults of the lesser grain borer, *R. dominica*, rice weevil, *S. oryzae*, and red flour beetle, *Tribolium* spp., were mass produced. The insects were fed with wheat flour and wheat grains as a diet. Twenty to thirty pairs of each insect species were placed in plastic jars containing 250 g of grains. A piece of kada cloth was secured to the jars with rubber bands. The cultures were kept in a controlled environment with a 12:12 hour light: dark photoperiod, temperatures between 26 and 28°C and relative humidity levels between 60 and 65 percent. All of the experiments were carried out under the identical circumstances where the cultures were kept in.

Olfactometer Bioassay

Four armed olfactometer apparatus: Three different odour sources such as wheat flour, sorghum flour and pearl millet flour were selected for olfactometer bioassay. To study the chemoreception and attraction, the experiment was conducted by way of an olfactometer apparatus. It consisted of square-shaped box with four horizontal side tubes. The plastic box (25 cm X 25 cm X 11.5 cm) was supported at the bottom by four supports with a removable top of the centre for the insertion of test insects. The protruded four arms from the plastic box were linked to the container which contained the odour samples. The air pumping system was linked to this volatile container to attract the test insects. To produce the vacuum, a suction pump was connected to the glass container independently. The corners of the plastic box were blocked to prevent insects from moving and resting in the corners, as well as to cause the insects to migrate towards their favourite volatiles. The olfactometer was first cleaned with 70% ethanol to minimize odour residue. Purified air was pumped into the four arms via Teflon tubes from an air delivery system for 45 minutes before and after each experiment, a vacuum was generated within the olfactometer to keep the volatiles from mixing.

Orientation studies of storage insects: Test insects viz., *R. dominica*, *Tribolium* spp. and *S. oryzae* were starved for 24 h in petri plates before the commencement of olfactory bioassay. Fifty unsexed adults were released in the centre of the olfactometer (7mm hole) and it was covered with cloth to minimise the phototactic response of insects. At 5, 10, 15, 20, 25 Minutes After Release (MAR), the location of the insects was observed (Vijay et al 2020). Each treatment was replicated 5 times. The response of *R. dominica*, *Tribolium* spp. and *S. cerealella* was assessed on wheat flour, sorghum flour and pearl millet flour. On each arm, the numbers of settled and unsettled insects were observed.

Volatile Profiling of Food Baits in GC-MS/MS

Sample preparation: GC-MS/MS spectroscopic analysis was performed to determine the exact active principles present in the attractive baits. For this purpose, a fresh sample of food baits was dried and ground into powder. Ten gram of the sample was extracted in an ultrasonic bath for 30 minutes with 30 ml of methanol and filtered through a 0.45 μm polyvinylidene fluoride syringe filter (Kim et al 2020).

GC- MS/MS analysis: Chemical profiling study was done at the Central Instrumental Laboratory, Department of Agricultural Entomology, Madurai where the methanol extract was characterized using a gas chromatograph-mass spectrometer (GC- MS/MS) (GC 2010 plus, GCMS – TQ 8040 SHIMADZU). On the capillary column (Rxi® - 5 Sil MS), the compounds were separated. The carrier gas was helium (purity percentage > 99.99%), with a column flow rate of 1ml/min and injection in split less mode. The oven temperature was set to 110°C, which was gradually increased to 150°C at a rate of 10°C/min and held for 5 minutes before being increased to 200°C at a rate of 10°C/min. After another 20 minutes, it was raised to 240°C at a rate of 10°C/min and held for 5 minutes. The MS was run in Electron ionisation (EI) mode at 70 eV, with an ion source temperature of 200°C, an interface temperature of 230 °C, and a scan range of 45-600 m/z. The solvent cut time was three minutes. Each sample was given 30 minutes to run. The NIST17 (National Institute of Standards and Technology) MS library database was used to identify the spectrum of the unknown volatile compounds. The obtained compounds were tabulated, along with the peak percent area and retention time (RT).

Statistical analysis: The data on attraction index and behavioural response/orientation of the beetles were statistically analysed using completely randomized design (CRD) by one-way ANOVA subjecting the data to arcsine/square root transformation and were separated by using Duncan's multiple range test (DMRT) with IBM SPSS statistics 22.0 software and differences were regarded as significant at $p < 0.05$.

RESULTS AND DISCUSSION

Behavioural response of insects: Based on the observation made in four arm olfactometer maximum preference percentage of *Tribolium* spp. was in wheat flour (32.66%) followed by sorghum flour (24.5%) and pearl millet flour 16% at 25 MAR. Olfactometer bioassay showed that at 25 MAR more *S. oryzae* (24.83%) settled in the test arm containing sorghum flour which was on par with wheat flour. Olfactometer bioassay revealed the significant variations on orientation/behavioural response of *R. dominica* towards wheat flour, sorghum flour, pearl millet flour and control (without food bait) in a four-arm olfactometer. At 25 Minutes

After Release (MAR), the highest orientation of 28.5% recorded towards wheat flour and found significantly superior to other flours followed by sorghum flour (21.16%) and pearl millet flour (17.5%) (Table 1). Vijay et al (2020) reported that the highest orientation of *S. oryzae* was towards sorghum (53.33% and 48.67%) in 20 MAR. While in our study the highest orientation of *S. oryzae* towards wheat flour as 31% and 39% of 20 and 25 MAR respectively, while 26% of *S. oryzae* settled in sorghum flour at 5 and 20 MAR. Trematerra et al (2000) observed that *O. surinamensis*, *T. castaneum*, and *T. confusum* use grain volatile odours to determine whether stored wheat grain kernels have been damaged mechanically or by insects and these studies are corroborative to our findings.

Identification of volatile profile of different food baits in GC-MS/MS: The separation of the volatile compound was obtained using the RX i – 5 Sil MS capillary column (Table 2). The 114 different compounds were detected in the methanolic food bait extract and components can be divided into 10 categories including 22 alcohols, 10 ketones, 7 aldehydes, 16 hydrocarbons, 14 esters, 3 ethers, 23 fatty acids, 5 nitrogenous compounds, 4 pyrans and 10 other group compounds. Among the various compounds detected 2.81, 0.58, 3.84, 1,0, 0.84 and 1.69 percent alcohol were present in the wheat, sorghum, pearl millet, groundnut, rice and rice bran respectively. The maximum ketones were present in wheat (2.15 %) and minimum in rice bran (0.14%). The highest amount of aldehyde presents in pearl millet (19.76%) followed by wheat and maize. The maximum hydrocarbons 6.57% were present in wheat and minimum 3.6% in rice. The higher amounts of esters present in groundnut (8.84%) followed by wheat, sorghum, rice bran, maize and rice (1.71%). Furthermore, 0.79%, 1.23% and 0.16% of ethers present in wheat, groundnut and maize, respectively. The greater amounts of fatty acids were identified in rice bran (68.88%) followed by sorghum, rice, pearl millet, wheat and maize. The least amounts of fatty

acids identified in groundnut were (18.94%). Nitrogenous compounds were present only in wheat, sorghum and groundnut (0.99, 0.73 and 0.8% respectively). Pyrans were present in wheat, sorghum, pearl millet and maize. Large amounts of other compounds were also identified in wheat (7.01%) followed by sorghum (4.73%) and groundnut (3.98%), and minimum in rice bran (0.87%) (Table 2).

Insects attracting volatile compounds: The attractive volatile compounds such as 1- butanol (0.25%), 3-octen-1-ol (0.24%), pentanal (0.32%), nonane (0.3%) and undecane (1.73%) were present in wheat, and were major attractants of *S. cerealella* and *S. oryzae* (Table 3) Sorghum have 3-hexanal (0.09%), 7-octen-4-one (0.12%) and butyric acid (0.10%) of volatile compounds which are responsible for the attraction of greater number of *R. dominica*, *Tribolium* spp. and *S. oryzae*. In pearl millet 7-octen-4-one (0.26%), 1-octanal (0.78%), hexanal (0.58%), butanal (0.24%), nonanal (1.55%) and undecane (0.73%) of attractive volatile compounds were present which responsible for the attraction of *O. surinamensis*. In groundnut and rice bran 0.18% and 0.34% of 3-hexanal present respectively, even though it attracted a smaller number of insect because other attractive volatile compounds are absent. Similarly, butanal (0.14%) was present in maize and 0.14% 7-octen-4-one was present in rice bran this also attracts less insects.

Insect repellent volatile compounds: The n-Hexadecanoic acid, cis-Vaccenic acid, propionic acid and pentadecanoic acid were present in the baits and acted as repellent. The highest quantity of cis-vaccenic acid was present in rice bran (59.06%) resulting more repellency. Repellent volatile compounds were absent in wheat excepting n-Hexadecanoic which was present in a lower amount (12.65%) compared with other food bait, which exhibited very high attraction per cent in wheat compared to others (Table 4).

Behavioural reactions of stored product insect: In the present analytical investigation, the presence of volatile chemicals such nonane, undecane, butanol, and 3-octen-1-ol in wheat flour (Fig. 1) had attracted *S. cerealella* and *S. oryzae*. E-2-nonenal and 4-ethylacetophenone compounds induced favourable responses in *S. granaries*, *O. surinamensis*, and *Cryptolestious ferrugineus*, hexanoic acid, 2-phenylethanol and E-3-octen-2-one had elicited a response for *O. surinamensis* and *S. granarius* confirming previous findings (Collins et al 2007). Balakrishnan et al (2017) reported a related findings that amongst biologically active compound groups, undecane, octanal, 1-hexen-3-ol, 2-heptanone, ethyl hexanoate and hexanoic acid elicited the strongest Electroantennographic (EAG) responses to *Tribolium castaneum*. The maximum attraction of *O.*

Table 1. Behavioural/orientation response of *Tribolium* spp., *Sitophilus oryzae* and *Rhyzopertha dominica* to various food attractants

Food attractants	*Tribolium* spp. settled (%)	*S. oryzae* settled (%)	*R. dominica* settled (%)
	20 MAR	20 MAR	20 MAR
Wheat flour	32.66	27.83	28.5
Sorghum flour	24.5	22.33	21.16
Pearl millet flour	16	16.5	17.5
Control (Without food)	3.66	4.33	4.83
Unsettled	23.16	29	28

*MAR- Minutes after release

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Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
Alcohol								
1.	3-Hexanol, 2-methyl-	-	0.09±0.0008	-	0.18±0.003	-	-	0.34±0.003
2.	Propargyl alcohol	-	0.11±0.0005	-	-	-	0.15±0.004	-
3.	2-Propanol, 1-propoxy-	-	-	-	0.64±0.174	-	-	-
4.	1-Penten-3-ol	0.27±0.003	-	-	-	-	-	-
5.	2,5-Hexanediol	-	-	-	0.18±0.002	-	-	-
6.	1-Butanol	0.25±0.004	-	-	-	-	-	-
7.	RS-2,3-hexanediol	0.17±0.004	-	-		-	0.11±0.002	0.28±0.007
8.	1,2-Butanediol	-	-	-	-	-	-	0.65±0.021
9.	2-Bromo-1,3-dicyclopropylpropane-1,3-diol	0.33±0.004	-	-	-	-	0.35±0.001	-
10.	2-Furanmethanediol	0.29±0.002	-	-	-	-	-	-
11.	1,14-Tetradecanediol	0.52±0.01	-	-	-	-	-	-
12.	3-Octen-1-ol	0.24±0.006			-	-	-	-
13.	5-Methyl-2-hexanol	0.23±0.005	-	-	-	-	-	-
14.	3-Ethyl-3-methyl-2-pentanol	0.51±0.002	-	-	-	-	-	-
15.	DL-2,3-Butanediol	-	0.10±0.002	0.21±0.005	-	-	-	-
16.	2,3-Epoxyhexanol	-	0.09±0.001	-	-	-	-	-
17.	(SS)- or (RR)-2,3-hexanediol	-	0.19±0.002	-	-	-	-	-
18.	(S)- (+)-Isoleucinol	-	-	0.19±0.002	-	-	-	-
19.	Cyclohexane propanol	-	-	0.88±0.010	-	-	-	-
20.	4-Ethyl-1-hexyn-3-ol	-	-	1.56±0.011	-	-	-	-
21.	1,7-Octanediol	-	-	0.81±0.016	-	-	-	-
22.	4-Dodecanol	-	-	0.19±0.0008	-	-	0.23±0.006	0.42±0.0002
Total Alcohol		2.81	0.58	3.84	1	0	0.84	1.69
Ketones								
23.	1,2-Dioxolan-3-one	-	-	-	0.41±0.005	-	-	-
24.	1,3-Dioxan-4-one,2-(1-methylethyl)-5-methyl		0.17±0.002		0.20±0.0024	0.07±0.0007	-	-
25.	Tetrahydro [2,2'] bifuranyl-5-one	0.14±0.001	-	-	-	-	-	-
26.	delta. -Nona lactone	-			1.21±0.0021	-	-	-
27.	Spirohexan-5-one	0.70±0.018	-	-	-	-	-	-
28.	Dihydro-2(3H)-thiophenone	-	-	-	0.75±0.003	-	-	-
29.	Cyclononanone	1.31±0.021	-	-	-	-	-	-
30.	7-Octen-4-one	-	0.12±0.0003	0.26±0.002	-	-	-	0.14±0.004
31.	2-Hydroxy-3-hexanone	-	0.14±0.004	-	-	-	-	-
32.	2-Nonanone	-	-	-	0.36±0.004	-	-	-
Total Ketones		2.15	0.43	0.26	2.93	0.07	0	0.14
Aldehydes								
33.	7-Tetradecenal	-	-	16.61±0.371	-	-	-	-
34.	1-Heptanal	0.19±0.002	-	-	-	-	-	-
35.	1-Octanal	-	-	0.78±0.005	-	-	-	-
36.	Pentanal	0.32±0.0005	-	-	-	-	-	-

Cont...

Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
37.	Hexanal	-	-	0.58±0.014	-	-	-	-
38.	Butanal	-	-	0.24±0.001	-	0.14±0.001	-	-
39.	Nonanal	-	-	1.55±0.008	-	-	-	-
Total Aldehydes		0.51	0	19.76	0	0.14	0	0
Hydrocarbons								
40.	2-Methoxy-2-methylbut-3-ene	-	0.10±0.002	-	0.18±0.001	-	-	-
41.	2-Pentene	-	-	0.34±0.003	-	-	-	-
42.	Nonadecane	-	1.24±0.033	-	-	-	-	-
43.	2-Bromononane	0.28±0.0001	-	-	-	-	-	-
44.	1-Bromodocosane	-	-	-	-	-	1.8±0.020	-
45.	Pentane	-	-	-	-	0.07±0.0007	0.30±0.007	-
46.	1-Hexyl-2-nitrocyclohexane	0.21±0.002	-	0.25±0.003	-	-	-	-
47.	Dodecane	-	-	-	-	-	1.5±0.009	-
48.	Nonane	0.3±0.005	-	-	-	-	-	-
49.	Octacosane	-	-	-	5±0.091	-	-	-
50.	Undecane	1.73±0.041	-	-	-	-	-	-
51.	Decane	3.86±0.020	-	-	-	-	-	-
52.	Cis-1-methyl-3-n-	0.19±0.003	-	-	-	-	-	-
53.	Heptane	-	0.16±0.0004	-	-	0.09±0.001	-	-
54.	4-Trifluoroacetoxyoctane	-	0.2±0.001	-	-	0.09±0.001	-	-
55.	Octadecane	-	3.8±0.109	-	-	-	-	-
Total Hydrocarbons		6.57	5.5	0.59	5.18	0.25	3.6	0
Esters								
56.	Glycidyl palmitate	1.1±0.029	-	-	-	-	-	-
57.	Methyl ester	2.81±0.022	1.58±0.028	-	-	1.03±0.20	-	-
58.	Pentyl ester	-	-	-	-	-	-	2.34±0.062
59.	Dineopentyl ester	-	0.09±0.001	-	-	-	0.12±0.002	-
60.	5-hexenyl ester	-	-	-	1.32±0.037	-	-	-
61.	1-cyclopentylethyl ester	0.75±0.012	0.15±0.001	-	-	-	0.31±0.001	-
62.	2-pentadecyl ester	-	-	-	3.8±0.020	-	-	-
63.	Dodecyl ester	0.15±0.001	-	-	-	-	-	-
64.	2-methoxyethyl ester	-	0.11±0.002	-	-	-	-	-
65.	Hexadecyl ester	0.32±0.008	-	-	-	-	-	-
66.	3-hexenyl ester	0.26±0.007	-	-	-	-	-	0.46±0.010
67.	Octadecyl 2-propyl ester	-	1.22±0.014	-	-	-	-	-
68.	2-hydroxy-1-(hydroxymethyl)ethyl ester	-	-	-	3.72±0.032	1.32±0.009	1.28±0.015	-
69.	(E)-But-2-en-1-yl 2-methylbutanoate		0.14±0.002	-	-	-	-	0.11±0.001
Total Esters		5.39	3.29	0	8.84	2.35	1.71	2.91
Fatty Acids								
70.	n-Hexadecanoic acid	12.65±0.022	15.42±0.181	20.36±0.512	13.46±0.109	19.45±0.344	13.47±0.174	-
71.	Oleic Acid	10.2±0.072	14.18±0.434	-	-	-	36.92±1.022	-
72.	Butyric acid	-	0.10±0.001	-	-	-	-	-
73.	linoleic acid	-	14.18±0.115	-	-	-	-	-
74.	Heptacosanoic acid	0.24±0.006	-	-	-	-	-	-

Cont...

Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
75.	2-Methylvaleric acid	-	-	1.66±0.046	-	-	-	-
76.	Hexanoic acid	-	-	0.57±0.001	-	-	-	-
77.	Valproic Acid	-	-	-	0.51±0.008	-	-	-
78.	Octanoic acid	-	0.34±0.004	-	-	-	-	-
79.	Pentadecanoic acid	-	-	-	0.88±0.014	-	-	-
80.	Butanoic acid	0.26±0.006	0.13±0.003	-	-	-	0.15±0.003	0.07±0.0009
81.	Tetradecanoic acid	1.81±0.042	1.2±0.032	1.22±0.012	0.79±0.011	0.91±0.003	3.33±0.058	1.29±0.022
82.	Tridecanoic acid	1.36±0.019	-	0.7±0.002	-	-	-	-
83.	cis-Vaccenic acid	-	-	-	-	-	-	59.06±0.174
84.	Octadecanoic acid	2.31±0.001	-	3.11±0.054	-	3.07±0.014	3.35±0.057	7.2±0.097
85.	Undecanoic acid, 10-bromo-	-	-	-	1.47±0.009	0.26±0.005	-	-
86.	2-Octenoic acid	-	-	-	-	1.29±0.037	-	0.30±0.004
87.	9-Octadecenoic acid	-	20.5±0.559	-	-	15.11±0.222	-	-
88.	Decanoic acid	-	0.69±0.003	-	-	-	-	-
89.	Tridecanoic acid	-	-	0.70±0.017	-	-	-	-
90.	11,14-Eicosadienoic acid	-	-	1.43±0.026	1.14±0.004	-	-	-
91.	9-Oxononanoic acid	-	-	-	0.69±0.002	-	-	0.96±0.005
92.	9,12-Octadecadienoic acid	13.65±0.369	-	18.35±0.075	-	-	-	-
Total fatty acids		42.48	66.4	48.1	18.94	40.09	57.22	68.88
Ethers								
93.	Chloromethyl octyl ether	-	-	-	1.23±0.028	-	-	-
94.	Allyl n-octyl ether	0.79±0.012	-	-	-	-	-	-
95.	Ethyl-1-propenyl ether	-	-	-	-	0.16±0.002	-	-
Total Ethers		0.79	0	0	1.23	0.16	0	0
Nitrogenous Compounds								
96.	o-Acetyl-L-serine	-	-	-	0.51±0.011	-	-	-
97.	Imidazole, 2- [[(. beta. - carboxy) propionyl] amine	0.27±0.006	-	-	0.29±0.003	-	-	-
98.	Hex-5-enylamine	0.45±0.006	-	-	-	-	-	-
99.	Isoxazole, 3,5-dimethyl-	0.27±0.003	-	-	-	-	-	-
100.	Pyrazol-4-amine, 1,5-dimethyl-	-	0.73±0.017	-	-	-	-	-
Total nitrogenous compounds		0.99	0.73	0	0.8	0	0	0
Pyrans								
101.	Tetra hydropyran	0.85±0.020	-	-	-	0.11±0.002	-	-
102.	6-(3-Methyl) butoxytetrahydro-2H-pyran	-	0.11±0.0002	0.23±0.005	-	-	-	-
103.	2H-Pyran,2-[(5-chloropentyl)oxy] tetrahydro-	-	-	0.17±0.003	-	-	-	-
104.	2H-Pyran, 2-(3-butynyloxy) tetrahydro-	0.34±0.003	-	-	-	-	-	-
Total Pyrans		1.19	0.11	0.4	0	0.11	0	0
Others								
105.	2,5-Dimethyl-1-pyrroline	0.21±0.001	-	0.22±0.004	-	-	-	-
106.	(S)-(+)-1-(2-Pyrrolidinylmethyl)-pyrrolidine	-	1.76±0.022	-	-	-	-	-
107.	1,4-Bis(tri methylsilyl)-1,3-butadiyne	2.12±0.027	-	-	-	-	-	-
108.	2-Pentyne, 5-methoxy-	0.20±0.003	-	0.22±0.004	-	-	-	-
109.	7,9-Di-tert-butyl-1-oxaspiro (4,5) deca-6,9-dien	4.18±0.061	2.64±0.015	2.29±0.006	3.98±0.063	1.96±0.040	2.56±0.004	0.75±0.002
110.	Furan, tetrahydro-2,5-dimethyl-	-	-	0.36±0.004	-	-	-	-
111.	Digitoxose	-	-	-	-	0.18±0.003	-	-
112.	Oxalic acid	-	0.21±0.006	0.17±0.003	-	-	-	0.12±0.001
113.	Propionic acid	-	0.12±0.001	0.23±0.002	-	-	-	-
114.	Phenol, 2-(1,1-dimethylethyl)-4-(1,1,3,3-tetra	0.30±0.001	-	-	-	-	-	-
Total others compounds		7.01	4.73	3.49	3.98	2.14	2.56	0.87
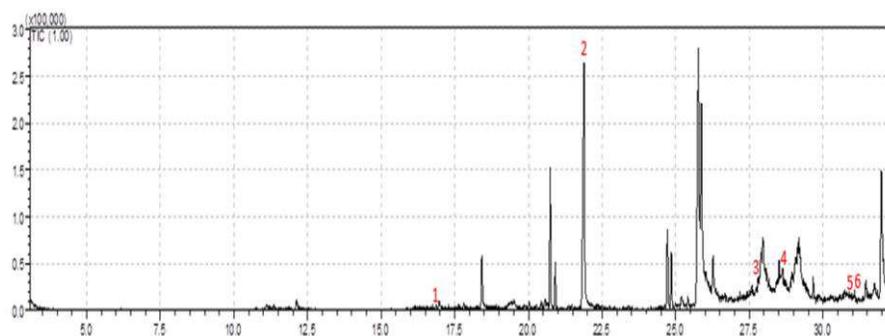
Fig. 1. Chromatogram of methanolic extract of wheat
1. Nonane, 2. n- Hexadecanoic acid, 3. Undecane, 4. 3-octen-1-ol, 5. Pentanal,
6. 1- Butanol
X axis – Retention time; Y axis – Intensity
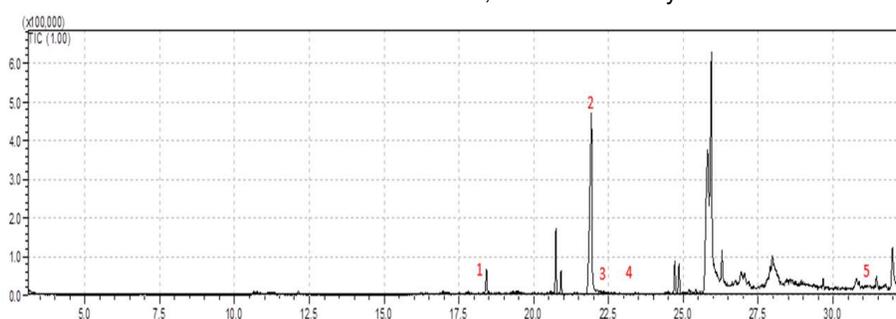
Fig. 2. Chromatogram of methanolic extract of sorghum
1. Propionic acid, 2. n- Hexadecanoic acid, 3. Butyric acid, 4. 3-Hexanol,
5. 7-octen-1-ol
X axis – Retention time; Y axis – Intensity

Table 3. Volatile compounds as insect attractants

Compounds	Peak area (%)						
	Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
3-Hexanol	-	0.09±0.0008	-	0.18±0.003	-	-	0.34±0.003
1-Butanol	0.25±0.004	-	-	-	-	-	-
3-Octen-1-ol	0.24±0.006			-	-	-	-
7-Octen-4-one	-	0.12±0.0003	0.26±0.002	-	-	-	0.14±0.004
1-Octanal	-	-	0.78±0.005	-	-	-	-
Pentanal	0.32±0.0005	-	-	-	-	-	-
Hexanal	-	-	0.58±0.014	-	-	-	-
Butanal	-	-	0.24±0.001	-	0.14±0.001	-	-
Butyric acid	-	0.10±0.001	-	-	-	-	-
Nonanal	-	-	1.55±0.008	-	-	-	-
Nonane	0.3±0.005	-	-	-	-	-	-
Undecane	1.73±0.029	-	0.73±0.009	-	-	-	-

Table 4. Volatile compounds as insect repellent

Compounds	Peak area (%)						
	Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
n-Hexadecanoic acid	12.65±0.022	15.42±0.181	20.36±0.512	13.46±0.109	19.45±0.344	13.47±0.174	-
Pentadecanoic acid	-	-	-	0.88±0.014	-	-	-
cis-Vaccenic acid	-	-	-	-	-	-	59.06±0.696
Propionic acid	-	0.12±0.001	0.23±0.002	-	-	-	-

surinamensis was due to some odour produced by pearl millet flour followed by wheat flour (Fig. 3). *T. confusum* and *S. oryzae* responses to plant extracts and pheromones were examined by Athanasius et al., (2006), where traps with baits like oil and seeds are more attractive than traps without bait.

T. castaneum female responded effectively towards common fungal semiochemicals such as 2-octanol, octan-3-ol, and 3-octanone. Earlier scientist reported that plant volatiles elicited responses in *R. dominica*, whereas wheat seeds elicited the strongest responses (Thakeow et al 2008; Holighaus et al 2014; Edde and Phillips 2006a). Adult granary weevils, *S. granarius* can respond behaviourally to a wide spectrum of cereal volatiles, and their responses can vary depending on concentration (Germinara et al 2008), which are related to present study. For *O. surinamensis* and *O. mercator*, several doses of benzaldehyde and aliphatic aldehyde were evaluated, and an estimated 10 aliphatic and benzaldehyde showed positive reaction in both species. Adults of *Callosobruchus sinensis* showed preference behaviour towards benzaldehyde and 2-hexanal (Wang et al 2020). *Callosobruchus maculatus* attracted to 3-octanol, linalool oxide, 3-octanone, nonanal and 1-octanol (Adhikary et al 2015). The attractive compounds like 3-hexanol and butanal present in groundnut and maize respectively (Fig. 4 &

5), 3-Hexanol and 7-octen-4-one present in rice bran whereas attractive compounds are absent but repellent compound cis- Vaccenic acid present in rice (Fig. 6). Ukeh and Umoetok (2011) reported that (R)-linalool and (S)-2-heptanol were stronger repellent volatile compounds than the others. Linalool showed good repellent activity against *T. castaneum*. Propionic acid, n-Hexadecanoic acid, cis-Vaccenic acid and pentadecanoic acid were acted as repellent. In our current study, cis-Vaccenic acid was present in rice bran (59.06%) (Fig. 7) and attraction per cent was very low towards this bait, whereas, n-Hexadecanoic acid was present in a lower amount in wheat (12.65%), which exhibited very high attraction per cent in wheat compared to others. Propionic acid absents in wheat, this is also reason wheat flour attracting more numbers of insects compared to other flours. Germinara et al (2007) reported that *Sitophilus oryzae* and *S. granarius* showed repellent effects towards propionic acid. Appalasamy et al (2021) observed that octadecanoic acid, pentadecanoic acid and cis- Vaccenic acid acted as repellent and insecticidal activity against termites, *Macrotermes carbonarius* and cockroaches, *Periplaneta americana,* which are comparable with our investigation. Sathiyaseelan et al (2022) reported that wheat, sorghum and pearl millet flour baits were tested and verified using four-arm
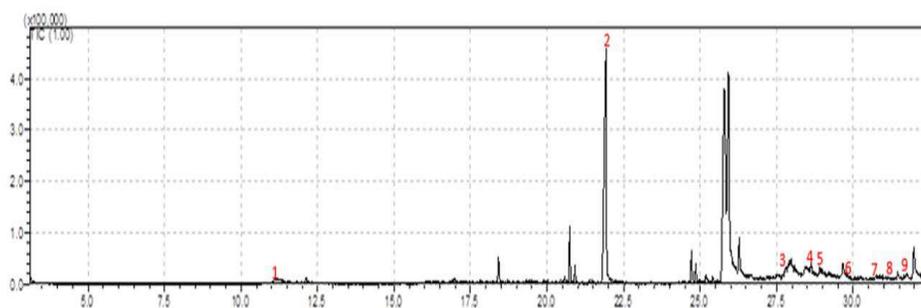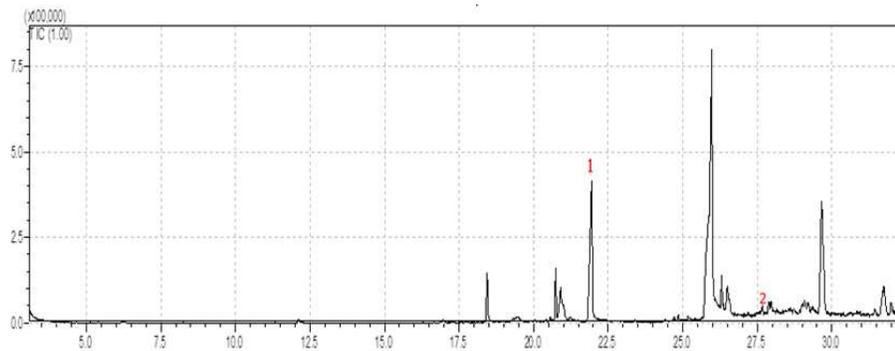

Fig. 3. Chromatogram of methanolic extract of pearl millet
1. Propionic acid, 2. n- Hexadecanoic acid, 3. Nonanal, 4. Nonane, 5. Hexanal, 6.
1-octanal, 7. Butanal, 8. 7-octen-4-one, 9. Hexanoic acid
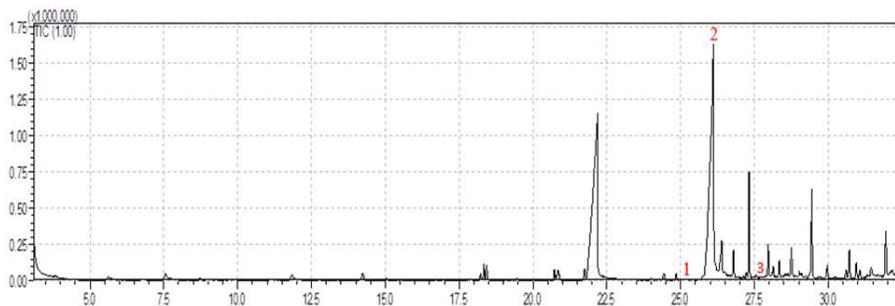X axis – Retention time; Y axis – Intensity
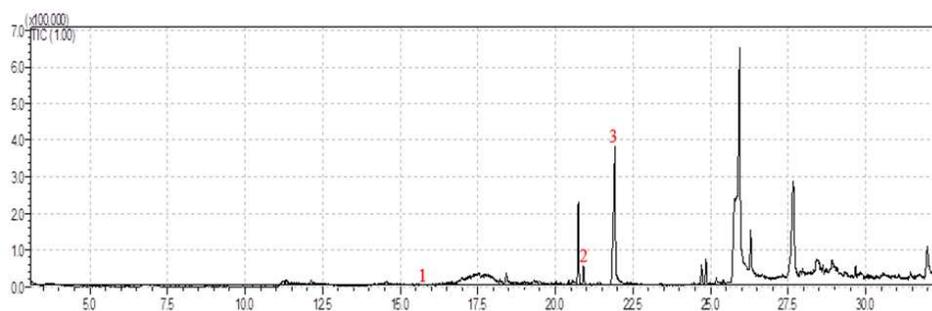
Fig. 4. Chromatogram of methanolic extract of groundnut
1. 3- Hexanol, 2. Pentadecanoic acid, 3. n- Hexadecanoic acid
X axis – Retention time; Y axis – Intensity
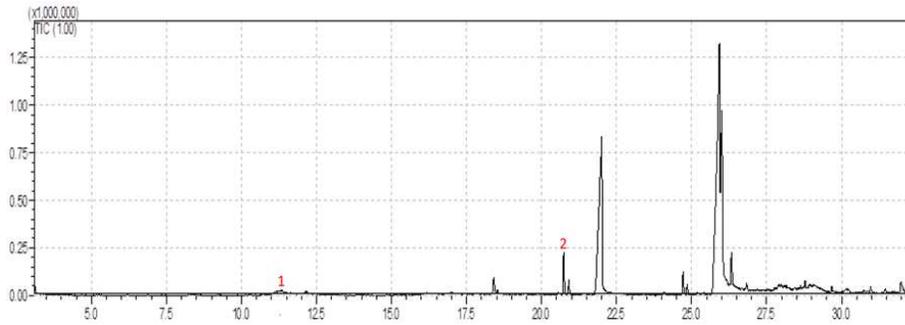
Fig. 5. Chromatogram of methanolic extract of corn
1. Butanal, 2. n- Hexadecanoic acid
X axis – Retention time; Y axis – Intensity

Fig. 6. Chromatogram of methanolic extract of rice
1. n- Hexadecanoic acid, 2. 3- Hexanol
X axis – Retention time; Y axis – Intensity

Fig. 7. Chromatogram of methanolic extract of rice bran
1. 7-octen-4-one, 2. Cis- Vaccenic acid, 3. 3- Hexanol
X axis – Retention time; Y axis – Intensity

olfactometer and the highest orientation was found in the arm containing wheat flour by attracting *S. oryzae, Triboliumi* sp. and *R. dominica* of 43.19,39.61 and 37.41% respectively which possessed nonane, undecane, 3-octen-1-ol, butanal and pentanal volatile compounds.

CONCLUSION

The attraction efficiency of different food baits to various storage insect pests from this present study emphasized that these attractants can be used to develop a multi-species lure for the control of stored pests economically and eco-friendly and thus the effective bait such as wheat flour, sorghum flour/cracked sorghum and pearl millet flour can be further exploited for monitoring and mass trapping of insect pests in rice godowns.

AUTHOR CONTRIBUTION

The study was conceptualised and designed by J. Jayaraj and M. Shanthi. M. Sathiyaseelan carried out the experiments and prepared the manuscript. K. Sujatha

assisted with the storage grain sample collection and data analysis. The article was read and approved by all the authors.

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Common Pool Resources Key to Sustainable Paddy Cultivation: Study from Drought-Prone Areas of West Bengal, India

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Abstract: In the context of agrarian distress, the present paper aims to study the role of common pool resources in sustaining paddy cultivation in drought-prone areas of West Bengal, India. The study uses primary data collected from 456 households across two districts, Bankura and Purulia, during 2022. Most of the landholdings were marginal and small. Return over total cost (C2) was negative, implying paddy cultivation on these landholdings was not economically viable. Return over paid-out cost (A1) was substantial, indicating common pool resources have a great role in sustaining paddy cultivation and making farming a viable livelihood option for large masses of rural poor people in drought-prone areas by increasing productivity and saving costs through supplementing inputs. Paddy productivity was higher in households whose principal activity was cultivation, had a large family, had larger plots, including more 'Bahal' or 'Kanali' types, had irrigation potential from common pool water resources, had bullocks, used high-yielding-variety seeds, and had savings. This important form of natural resource is gradually degrading. Proper maintenance of common pool water resources, grazing land, and village forests with people's participation will be necessary for the sustainability of paddy cultivation in drought-prone areas.

Keywords: Common pool resources, Cost of cultivation scheme, Paddy cultivation, Sustainability, Sustainable livelihood approach

Agriculture and allied sectors are the backbone of the Indian economy. The majority of Indian people depended on it for their food and livelihoods. During the last two decades, Indian agriculture has faced severe crises and stagnation. The average annual growth of the agriculture and allied sectors during the 12th Five Year Plan (2012-17) at 1.6 percent fell short of the target of 4 percent, which was lower than the average annual growth of 3.6 percent, 2.4 percent, and 2.5 percent achieved during the 11th, 10th, and 9th five-year plans, respectively (Govt. of India 2018). The average size of landholdings is gradually decreasing. It has decreased from 0.725 ha in 2003 to 0.592 ha in 2013 and further to 0.512 ha in 2019 (NSSO 2021). Most of these landholdings are fragmented. Farmers got a lower price for their produce compared to non-farm products. The contribution of income from cultivation to the total household income of farmers has declined from 48% in 2014 to 37% in 2019. Side by side, agricultural productivity in India is much lower compared to other countries. Again, the increasing cost of cultivation added a major threat to the sustainability of agriculture and the livelihoods of the people dependent on it. As a result, land-based rural livelihoods and the food security of small and marginal farmers are becoming increasingly unsustainable. According to a survey by 'Pratham,' an NGO, the average age of farmers is now nearly 50 years old, and they are going to retire (Mahapatra 2020). The next generation is unwilling to continue agriculture. Behind the highlights of the green revolution, there are some regions and some poor farmers who are still using traditional methods of cultivation using bullock labour on their small and marginal plots of land. The sustainability of agriculture is of the utmost necessity for the survival of these large masses of the Indian population, whose lives are based on biomass. Rice is the main staple food of the Indian people. West Bengal is the top producer of paddy in India. Major paddy-producing areas of West Bengal are still dependent on the monsoon. Now there arises a question: is paddy cultivation sustainable in the drought-prone areas of West Bengal? Past literature did not give us a comprehensive picture of how the poor people of Bankura and Purulia districts of West Bengal cope with a variety of risks and shocks in meeting their food and livelihood security while sustaining paddy cultivation. As the green revolution badly affects the environment and soil characteristics (Mishra 2013), the Government of India launched the Bharatiya Prakritik Krishi Paddhati Programme (BPKP) to promote eco-friendly, less water-consuming "Natural Farming," which is based on farm biomass recycling, the use of manure, and the use of bio-pesticides to restore soil organic matter, soil fertility, and the elimination of chemical fertiliser and pesticides. Common Pool Resources (CPRs) are subsets of renewable natural resources commonly used by an identifiable community, either by de

facto or by de jure sense. Modern agricultural practice investigates the conservation of soil and water, raising the productivity of cropland, and reducing agricultural waste. This requires a systematic compilation of natural resources, land use patterns, cropping systems, and production levels to understand their relationship between constraints and potentials under existing agro-climatic conditions (Patel et al 2020). In this context, the objective of the present study is to analyse the role of common pool resources (CPRs) in sustaining paddy cultivation across drought-prone areas of Bankura and Purulia district of West Bengal.

MATERIAL AND METHODS

The study uses primary data collected from 456 households across 16 villages over 8 development blocks in Bankura and Purulia district of West Bengal in India in 2022. These two districts are drought prone in nature(Bhunia et al, 2020). Blocks and villages were selected using the stratified sampling method. The basis of stratification was the concentration of the scheduled caste (SC) and scheduled tribe (ST) populations and the prevalence of CPRs. The distribution of sample households is given in Table 1. The structured questionnaire was used for data collection during the survey. Side by side, interviews with some elderly and knowledgeable people were conducted about the various issues of paddy cultivation and CPRs.

Profile of location: Two drought-prone districts, Bankura and Purulia, are located in an undulating red and laterite zone in the western part of West Bengal (Gorai and Modak 2020, District of Bankura 2020 and District of Purulia 2021). The lands in these two districts are covered with interspersed hillocks, laterite ridges, and sparse forest growth. The formation of soil occurs by weathering bad rocks, contains little organic matter, and is porous in nature. Therefore, the water-holding capacity of the soil is low. The fertility of the soils in these two districts is very poor. Mono-cropping "Aman" paddy is predominantly cultivated. The southwest monsoon regulates the rain, which is erratic and leads to crop failure regularly. Paddy fields are classified as 'Bahal' (low-level land), 'Kanali' (medium-level land), and "Baid' (high-level land) (Roy and Jana 2019). 'Bahal' is always wet from the percolation of the pond. It is composed of rich alluvial soil and is highly fertile (Mahato 2015). "Kanali" is a large stretch of terraced land that lies between Bahal and Baid. It is of medium quality in terms of fertility and moisture content. "Baid" is situated on the upper level. It contains mostly laterite and sand, and thereby its moisture-holding capacity as well as fertility level is also very low. There is negligible scope for employment other than in agriculture and allied sectors in Bankura and Purulia districts.

Methodology: The study uses the Sustainable Livelihoods Approach (SLA) of DFID (1999) to assess the effectiveness of CPRs towards the sustainable agriculture practices and livelihoods of the people depending on them (DFID 1999, Natarajan et al 2022). Variation in production, productivity, price, and cost per unit of paddy production between households depends upon the composition and strength of the asset pentagon of households. These five assets are *human* capital, physical capital, financial capital, natural capital, and social capital (Dutta and Guchhait 2018). The present study identifies some specific components of each asset (Fig. 1).

In order to investigate the cost-benefit analysis intensively, the study classified the sample households into two stages: 1) according to their principal source of earnings. 2) according to their operational holdings. As per the National Sample Survey (NSSO 2014), the principal sources of earnings are:

1) Self-employed in agriculture (C)
2) Non-Agricultural Labour (NAL) who engaged in casual

Table 1. Distribution of sample households

Blocks	Village	No. of households	% of SC, ST	Blocks	Village	No. of households	% of SC, ST
		Bankura				Purulia	
Chhatna	Jamthol	28	75	Arsha	Siridi	26	47
Chhatna	Kalipur	27	61	Arsha	Gundligora	28	76
Saltora	Jhanka	31	79	Para	Beryadi	21	79
Saltora	Bamnishala	29	69	Para	Kelahi	28	35
Hirbandh	Talgaria	30	77	Hura	Pakhuria	26	65
Hirbandh	Uganpathar	32	71	Hura	Matipur	30	69
Rani Bandh	Nachna	33	78	Bandwan	Burijhor	25	91
Rani Bandh	Bauripal	30	37	Bandwan	Dhadka	32	42
	Total	240				216	

Source: Computed by authors from primary data

non-agriculture work

3) Self-employed in non-agricultural work (SNA) who engaged in small business and trading

4) Agricultural Labour (AL), who engaged in casual agriculture work and

5) Regular salaried jobs (RS) in the formal sector (private and government)

Secondly, households were classified according to their possession of operational land holdings (own land +leased-in land + leased-out land). These are: 0.01-0.40 ha, 0.41-1.00 ha, 1.01-2.00 ha, and 2.00-4.00 ha (NSSO 2014).

Variation in the cost of cultivation of paddy is analysed following the guidelines of the scheme of cost of cultivation, Government of India (Govt. of India 2023). These are

Cost A1 = all actual expenses in cash and kind incurred = operational cost = paid-out cost

Cost A2 = Cost A1+ Rent paid for leased-in land

Cost B1 = cost A1+ interest on the value of owned capital assets

Cost B2 = cost B1+ imputed rental value of owned land and rent paid for leased-in land

Cost C1 = cost B1+ imputed wage of family labour engaged in cultivation

Cost C2 = cost B2+ imputed wage of family labour engaged in cultivation

Determinants of productivity are identified by a dummy variable multiple regression model as follows: $Y = \alpha + \beta X_i +$

$\gamma D_i + \mu_i$

Where dependent variable Y = productivity of paddy (kg/ha), X_i are explanatory variables, D_i are dummy explanatory variables, and error term

Common pool resources: The present study focuses on those components of common pool resources (CPRs) that supplement the inputs of paddy cultivation. These components of CPRs are grazing land for feeding bullocks and collecting cow dung, common pool water resources (such as ponds, rivers, and rivulets) for irrigation, and village forests and woodlots for timber.

RESULTS AND DISCUSSION

Land holdings: The average land holding size among sample households was 0.6097 ha (Table 2) and considerable proportion of households (22.15%) were landless. Most households (34.87%) possessed cultivable land in the range of 0.41-1.00 ha. The second major land holding category was 0.01-0.40 ha, consisting of 25 percent of households. These two classes (58%) together constitute marginal land holdings. Small holdings constitute 16.67 percent of households. Hence, 75 percent of households possessed either marginal or small land holdings. Only 3 percent of households possessed medium land holdings within the range of 2.01-4.00. Landless households were higher in the Purulia district compared to the district. In both districts, the land holdings of the majority of households were marginal.

Cost-benefit analysis: economic viability of marginal and small holdings: In the analysis, NAL and SNA were clubbed to a group of non-agricultural workers (NAL). The number of samples in regular salaried jobs was too small, so we dropped this category from analysis. Only medium farmers got positive returns over total cost (C2). All other categories of households recorded negative returns, which means losses in terms of C2. The net farm income (which is the value of output over total cost) was negative. Therefore, marginal, and small land holdings in drought-prone areas of
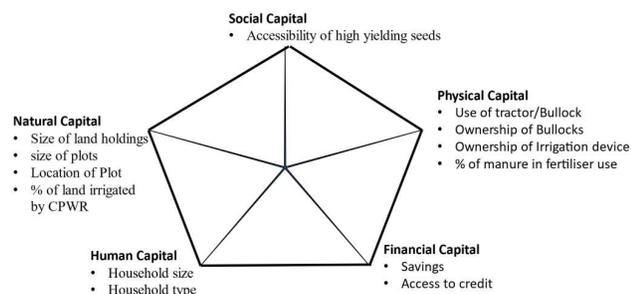
Social Capital
- Accessibility of high yielding seeds

Physical Capital
- Use of tractor/Bullock
- Ownership of Bullocks
- Ownership of Irrigation device
- % of manure in fertiliser use

Natural Capital
- Size of land holdings
- size of plots
- Location of Plot
- % of land irrigated by CPWR

Financial Capital
- Savings
- Access to credit

Human Capital
- Household size
- Household type

Fig. 1. Asset pentagon

Table 2. Average land holding size across households classified by size of operational holdings

Operational holdings (ha)	Bankura			Purulia			Combined		
	No. of households	Percent of households	Size of land (ha)	No. of households	Percent of households	Size of land (ha)	No. of households	Percent of households	Size of land (ha)
<0.01 (Land less)	46	19.17	0	55	25.46	0	101	22.15	0
0.01-0.40	58	24.17	0.1875	48	22.22	0.1984	106	23.25	0.1924
0.41-1.00	77	32.08	0.692	82	37.96	0.6885	159	34.87	0.6902
1.01-2.00	49	20.42	1.5729	27	12.5	1.4626	76	16.67	1.5337
2.01-4.00	10	4.17	2.174	4	1.85	2.396	14	3.07	2.2374
Total	240	100	0.679	216	100	0.5327	456	100	0.6097

Source: Computed by authors from primary data

Bankura and Purulia districts are not economically viable. Return over cost B2 was positive for each household, which indicates the great role of family labour in sustaining agricultural activity. This return varies from 30 percent to 70 percent over cost B2. Cost A1 is the operational cost of production, which includes all actual expenses in cash and kind. Gross farm income was positive and substantial. The percentage of gross income over paid-out cost, i.e., return over cost A1, ranged from 114 to 197 percent. If we exclude the imputed rental value of land and the imputed wage of family labour engaged in paddy production from the total cost, then the households get an attractive return over cost. This implies that paddy cultivation gives rural people an opportunity to use their land and labour in productive activities to earn income from agriculture.

Factors affecting the productivity of paddy- dummy variable multiple regression model: The estimated productivity of paddy ranged from 2143 to 4436 kg/ha for different categories of households (Table 3). The estimated P value and R square of the model indicate that the estimated overall regression model is highly significant (Table 4). Among the three household types, self-employed in agriculture (C) was taken as the base group. The yield rate was negative for AL and significantly negative for NAL. Therefore, the yield rate of paddy was higher for households whose principal activity was cultivation. Household size had a positive and significant relationship with productivity. The positive coefficient of operational holdings and size of plot shows that the productivity of paddy in drought-prone Bankura and Purulia districts increases with an increase in the size of operational holdings and size of plot. The location of the plot shows that the 'Bahal' type of plot was highly productive, followed by 'Kanali' and 'Baid'. With increasing

accessibility of common pool water resources (CPWRs), there was a higher chance of raising the productivity of paddy in drought-prone Bankura and Purulia districts. Similar results in another study of Purulia by Gorai and Modak (2020). The coefficient of technology was statistically significant, but the coefficient of irrigation devices and manure was insignificant. It indicates that there are higher chances of increasing yield when land is tilled with mechanised farming using a tractor compared to traditional farming using bullock labour. Among those households that use bullock labour for tilling, the probability of yield is higher for households that cultivate land with their own bullock compared to cultivating land by hiring bullock labour. In Himachal Pradesh, conventional tillage significantly increased grain yield (Seth and Manuja 2022). The estimated coefficient of improved seeds was positive and highly significant. It implies that the availability of high-yielding varieties (HYV) of seeds, either from neighbours or from panchayats, will produce more paddy per ha of land.

Inherent mechanism of sustainable paddy cultivation: Most of the lands possessed by households who were self-employed in agriculture (C) and possessing 0.01-0.40 ha of land were 'Baid, which have poorer fertility. They tilled their own land with their own bullock labour. To reduce costs and raise productivity, they used manure and exchanged HYV seeds with neighbours. They irrigated their land with common pool water resources (doba, pond, paddy field well, natural spring, etc.) with a small pump. The estimated average productivity was 3177 kg/ha, and the net return over total cost (C2) was negative (-23.3%) (Table 3). The main cost of cultivation is labour. Limited opportunities in the labour market in Bankura and Purulia districts induce family labour to engage in farming. Even children and elderly members

Table 3. Revenue, cost, and return on paddy cultivation across households

Type of households	Operational holdings (ha)	No. of HH	Yield kg /ha	Price of paddy (Rs/kg)	Revenue Rs/ha	Cost Rs /ha			Percentage of return over			Contribution of	
						Cost C2	Cost B2	Cost A1	Cost C2	Cost B2	Cost A1	Rs/ha	% of cost A1
C	0.01-0.40	11	3177	19.00	63484	82796	39404	23829	-23.3	61.1	166.4	18167	76.2
	0.41-1.00	84	3645	19.00	72517	88976	43123	24433	-18.5	68.2	196.8	15709	64.3
	1.01-2.00	40	3738	20.40	79682	86049	49292	30602	-7.4	61.7	160.4	11195	36.6
	2.01-4.00	14	4436	20.40	94072	68924	55467	36777	36.5	69.6	155.8	10884	29.6
NAL & SNA	0.01-0.40	49	2617	19.00	52830	84939	40239	24664	-37.8	31.3	114.2	2187	8.9
	0.41-1.00	51	2947	19.00	59104	82962	37707	22132	-28.8	56.7	167.1	1533	6.9
AL	0.01-0.40	46	2143	19.00	43211	73269	33148	17573	-41.0	30.4	145.9	0	0.0
	0.41-1.00	24	2585	19.00	52239	80259	37272	21697	-34.9	40.2	140.8	13413	61.8
	1.01-2.00	9	3140	19.00	62773	85977	38224	19534	-27.0	64.2	221.4	12881	65.9
		345											

Source: Computed by authors from primary data, note: HH= households

were also engaged in farming. If the imputed value of family labour engaged in cultivation is excluded, the cost of cultivation will go down, and the gross return will be 61.1 percent over cost B2. As they had their own land, they did not have to pay rent. As a result, the return over the cost of A1 was 166.4 percent. Therefore, marginal farmers made their cultivation sustainable. They rented their excess human labour and bullock labour force for tilling land or drawing carts and earned cash income. To rear bullocks, these households mostly depended on grazing land. The possession of bullocks along with other cattle produces manure, which is used to increase the fertility of the soil and reduce the cost of fertilizer. They made their own implements of cultivation, such as ploughs, carts, etc., using raw materials from the village woodlots. The cost of cultivation was saved due to the supplementary contribution of different components of CPRs, which was estimated at 76.2 percent of the material cost of cultivation (A1).

In this way, different types of households (according to principal activity) with varied amounts of cultivable land (including different location and size of plot) try to make their farming sustainable to sustain their livelihoods. The availability and accessibility of supplementary inputs from CPRs, coupled with other assets (components of asset pentagon), helped to increase productivity, stabilise production, and save the cost of cultivation considerably(Table 3).

Market price and minimum support price (MSP): In order to provide a favourable price for paddy, the government announces the minimum support price (MSP) every year. In 2022–23, MSP was Rs 20.40 per kg of paddy. But the local market price of paddy at that time was Rs. 19.00 per kg. Only 15 percent of the sample households were able to sell their paddy to the government at MSP and got Rs 20.40 per kg (Table 3). Bargadars, sharecroppers, marginal, and small farmers did not get the benefits of MSP in terms of price and timing.

Contribution of Common Pool Resources (CPRs) to Sustainable Paddy Cultivation

Saving cost and raising income: Those sample households possessed operational holdings; 89.85 percent of them got resource support from CPRs as supplementary inputs in paddy cultivation. The average contribution of CPRs in paddy cultivation was 35 percent of the material cost (Cost A1) (Table 3). The saving cost in turn reduces dependency on money lenders and exploitation by money lenders. Common pool water resources play a great role in combating drought-like situations by supplying surface water for irrigation, stabilising

Table 4. Factors of productivity: Result of dummy variable multiple regression model

Asset pentagon	Explanatory variables	Code	Coef.	Std. Err.	t	P>|t|
Human capital	Household size	hh_size	1.835	0.59	3.11	0.069
	Household type Agriculture labour yes=1, otherwise=0	Al	-0.84	1.679	-0.5	0.760
	Non-agriculture labour yes=1, otherwise=0	Nal	-2.364	1.209	-1.96	0.079
Natural capital	Size of operational holdings	Land	3.9	0.314	12.42	0.000
	The average size of plots	Plot_size	6.752	2.154	3.13	0.002
	Location of plot, Baid=1, Kanali=2, Bahal=3	Plot location	4.6023	2.026	2.27	0.029
	% of land irrigated by CPWRs	Irrigated	0.538	0.12	4.48	0.004
Physical capital	Bullock=0, tractor=1	Technology	11.181	2.436	4.58	0.000
	Bullock own=1, hired=0	Own bull	3.025	1.446	2.17	0.029
	own irrigation device yes=1, no=0	Pump	0.017	0.372	0.05	0.874
	% of Manure in fertiliser	Manure	0.143	0.531	0.27	0.457
Financial capital	Savings yes=1, no=0	Saving	0.052	0.01	5.2	0.000
	accessibility of credit y=1, no=0	Credit	0.725	2.094	0.35	0.795
Social capital`	Availability of high yielding variety seeds y=1, no=0	Improved seed	0.289	0.1039	2.78	0.002
	_Cons		-9.524	3.184	-2.99	0.002
Prob > F= 0.000				R-squared= 0.694		
Number of observations = 345				Adj R-squared = 0.612		

Source: Computed by authors from primary data

agricultural production, and raising productivity and farm income. CPRs provide the opportunity to use idle land and the labour force to mobilise productive activity and raise household income. Thus, paddy cultivation will be remunerative.

CPRs and PPRs linkage: Households have more private property resources (PPRs), like more family members, ownership of bullocks, pump sets, and cultivable land. They extract more benefits (tilling soil, harvesting crops, using manure, and irrigation) from CPRs by utilising different components of CPRs. Hence, there is a strong positive relationship and complementary role between CPRs and PPRs in paddy cultivation, mainly in the biomass-based subsistence economy, and without PPRs, CPRs become insignificant. A similar result was found in the study of Das and Kumar (2022). Respondents and elders in the sample villages mentioned that the availability, productivity, and accessibility of grazing land and water resources are gradually degrading. It demands proper maintenance to restore and recharge CPRs and enhance productivity. It needs the active participation of all users (villagers).

CONCLUSION

The study estimated that 22.15 percent of sample households in SC and ST-dominated drought-prone areas of the Bankura and Purulia districts are landless. 75% of households' land holdings were marginal and small, with an average size of 0.6097 ha. Net farm income was negative, which indicates that tiny plots of land were not economically viable. Farming was done mainly with family labour. Excluding the imputed value of family labour, they got positive returns ranging from 30 to 70 percent. The return varies by type of household and size of holdings. The estimated productivity of paddy was higher in households whose principal activity was cultivation, more family members, larger plots of land with more 'Bahal' or 'Kanali' types, irrigation potential from common pool water resources, , used HYV seeds. Only 15 percent of households were able to sell their crops to the government at MSP. Common pool resources (grazing land, water resources, and forests) act as supplements to the household's physical assets (land, bullocks, irrigation devices, and family labour) for sustaining paddy cultivation by reducing cost, improving soil health and productivity, and combating the drought-like situation. It saves 7 to 76 percent of operational costs. The supplementary role of CPRs provides the opportunity to use idle land and labour to mobilise productive activity and raise household income. In the era of distressed farming CPRs act

as shock absorbers. This important form of natural resource is gradually degrading. Proper maintenance of CPRs with people's participation is of the utmost necessity to recharge and sustain CPRs for the sustainability of paddy cultivation in the Bankura and Purulia districts of West Bengal.

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Biological Management of *Fusarium* Wilt of Tomato caused by *Fusarium oxysporum* f. sp*. lycopersici*

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Abstract: The *Fusarium* wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici* (FOL) is a soil borne pathogen. Biological control of soil-borne plant pathogens through antagonist organisms can be a convenient method in control of disease. The fungal bioagents (*Trichoderma harzianum and T. asperellum*) and bacterial bioagents (*Pseudomonas fluorescens* and *Bacillus* sp.) were tested for the management of *Fusarium* wilt of tomato caused by FOL under greenhouse condition. *T. harzianum* was superior in controlling the fungal wilt, followed by *P. fluorescens* compared to biocontrol by *Bacillus* sp. and chemical control by Mancozeb (75% WP). The application of *T. harzianum* exhibited the least disease incidence (25.43%). *T. harzianum* treatment resulted in better plant growth (plant height 105.13 cm, number of leaves per plant 71.12, main stem girth2.55 cm, leaf area 45 cm^2) and increased yield contributing parameters and yields in tomato when compared to other treatments. *Trichoderma harzianum* is a potential alternate to chemical control of tomato wilt disease.

Keywords: Biocontrol, *Fusarium* wilt, *Trichoderma harzianum,* Tomato

Tomato (*Solanum lycopersicum* L.) is an important solanaceous vegetable crop grown throughout the world, mainly in the warm seasons and can tolerate heat and drought reasonably, however it is grown under wide range of climatic conditions (Anonymous 2009). In India, estimated area, production and productivity during 2020-21 was about 840.33 thousand hectares, 20331 thousand tonnes, 24.20 tonnes/ha, respectively. Karnataka state ranks third in area (70.10 thousand hectares) and production (2104.68 thousand tonnes) with productivity of 30.00 tonnes/ha. In Karnataka, Bangalore and Kolar districts are the major tomato growing districts (Anonymous 2022), are affected by fusarium wilt caused by fungus, *Fusarium oxysporum* f. sp. *lycopersici* (Sayed Farooq Mahboobi et al 2023). The pathogen is very destructive causing 10 to 50 per cent yield loss in some tomato production areas (Ghazalibiglar et al 2016). It is very difficult to control fungal wilt of tomato, since the pathogen can progress within the vascular tissue by limiting the effectiveness of fungicides. However, biological control of this soil borne plant pathogen through antagonistic microorganisms can be an effective and alternative approach.

Different mechanism have been proposed to describe the biocontrol of plant pathogens by biocontrol agents, which include secretion of antibiotics, production of HCN, syderophores and, cell wall hydrolysing enzymes, competition for key nutrients, parasitism / stimulation of plant defence mechanisms and combination of all these possibilities (Taghdi et al 2015). Use of antagonist and plant growth promoting rhizobacteria (Schmidt et al 2004) such as *Bacillus, Enterobacter* and *Pseudomonas* strains, can encourage plant defenses. Similarly, fungal biocontrol agents, *Trichoderma* spp. are known to decrease the severity of plant disease by inhibiting plant pathogens in the soil through their great potent antagonistic and mycoparasitic activity (Viterbo and Horwitz 2010). Therefore, the evaluation of antagonists in the management of *Fusarium* wilt of tomato under greenhouse conditions was performed with fungal bioagents *viz*. *Trichoderma harzianum and Trichoderma asperellum* and bacterial bioagents *viz. Pseudomonas fluorescens* and *Bacillus* sp.

MATERIAL AND METHODS

The present study on biological management of *Fusarium* wilt of tomato was carried out in the polyhouse at University of Horticultural Sciences campus, Bengaluru situated at a Latitude 12º 581 North, longitude of 77º 351 East and altitude of 899 meters above mean sea level during the year 2019-20. ***In vitro* evaluation:** Sixty fungal and sixty bacterial biocontrol agents isolated from rhizosphere soils of tomato of three districts of Karnataka, namely Bengaluru rural, Chikkaballapur and Kolar. These isolates were screened for their efficiency to

inhibit *Fusarium oxysporum* f. sp. *lycopersici* by dual culture method on potato dextrose agar (PDA) for fungus and nutrient agar (NA)medium for bacteria against pathogen, After five days incubation, the zone of inhibition was measured to assess the efficacy of the biocontrol agents. The fungal cultures were maintained on PDA (Rahimi et al 2019) and the bacterial cultures on NA media. Two efficient fungal biocontrol agents *viz*., *T. asperellium* and *T. harzianum,* two efficient bacterial antagonistic isolates *viz*., *Psudomonas fluorescens* and *Bacillus spp.* (Sayed Farooq Mahboobi et al 2023) were selected for further scale up studies using grow bags culture against *Fusarium oxysporum* f. sp. *lycopesici* (*Fusarium* wilt of tomato).

Grow bag culture studies: *Trichoderma asperellium* and *T. harzianum,* pure cultures grown in potato dextrose broth, mixed with sterilized talc powder to obtain 10^9 conidia per gram of talc powder. Similarly, the bacterial isolates *Pseudromons fluorescens* and *Bacillus* sp. multiplied on nutrient broth mixed with carrier material (talc) to have 10^9 CFU per gram. These biocontrol agents were tested along with one positive control treatment with Mancozeb 75% WP and another negative control treatment (without biologicals or chemical). Soil was mixed with FYM @ 3:1 (w/w), sterilized for 5 days by formaldehyde fumigation, filled to grow bags of 15 cm x 20 cm (10 kg). The soil medium was inoculated individually with biocontrol agents @ 2% or 20 ml per bag, followed by root dipping. Twenty-five days old tomato seedlings of variety Arka Vikas, were dipped in their respective formulation of biocontrol agents for 30 minutes transplanted at the rate of three seedlings per grow bag (10 kg capacity) (Patil et al 2011). Mancozeb 75% WP @ 2 ml per liter was used as foliar spray as well as soil drench. To test biocontrol by different agents, all the treated plants in grow bags were challenge inoculated by the wilt fungi, *Fusarium oxysporum* f. sp. *lycopesici*, @ 5 per cent (w/w) using talk based formulation as soil drenching at 25 and 45 days after transplantation. Before inoculation, the roots were slightly severed (wounded) by inserting a needle 1 cm away from the stem. Root severing was done to ensure pathogen penetration through roots. Observations were recorded on wilt symptoms up to 5 weeks. The soil was made sick by mixing of pathogen culture in upper 10-15 cm layer of the soil.

The disease incidence of wilt was measured at 30 , 60 and 90 DAT at harvest (PDI), based on number of plants that showed symptoms of wilting as a percentage of the total number of plants. Subsequently, the disease ratings were plotted over time to generate the disease progress curves. Symptoms of *Fusarium* wilt disease were assessed every 10 days using disease scale (0 – 4). The plant was considered infected when a rating of 2 was recorded. The disease incidence was based on the infection percentage [I (%) = (number of plants infected / total number of plants observed) x 100]. The assessment of the disease severity was calculated [(S (%) = ($\sum$ [E.a] / N.T 100)]. where, E is the disease scale (0 to 4) for tomato wilt and a, is the number of plants infected at each symptomatological scale, N is the total number of plants observed and T is the maximum disease scale (4 for tomato wilt).

Plant height, number of leaves, diameter of stem, leaf area at 90 days after transplanting (DAT), average weight of fruits, number of fruits and yield per plant, fresh weight of shoot and root and dry weight of shoot and root per plant were recorded by following standard procedures. Each treatment was replicated twice in completely randomized design (the data was statistically analyzed using excel spread sheet for significance at 5 per cent critical difference as described by Gomez and Gomez (1983).

RESULTS AND DISCUSSION

In vitro **evaluation:** The dual plate screening of fungal and bacterial biocontrol agents (BCA) against *Fusarium oxysporum* f. sp. *lycopersici* significantly inhibited the growth of the fungal wilt. (Table 1). The per cent inhibition in mycelial growth of the fungal wilt ranged between 39.10 and 49.86 per cent. *Trichoderma harzianum* was most effective and significantly inhibited the mycelial growth of the *Fusarium*(followed by *Pseudomonas fluorescens*. The chemical fungicide Mancozeb 75% WP showed inhibition of 37%.

Disease incidence under polyhouse: All treatments (biocontrol and chemical control) decreased the fungal wilt incidence significantly over control (Table 2). Soil application of *Trichoderma harzianum,* talc formulation was most effective than chemical, Mancozeb and resulted in significant reduction in *Fusarium* wilt incidence. The wilt incidence observed in the grow bags with *T. harzianum* treatment was 25.43 per cent as compared to 65.23 per cent in the control treatment. The *T. harzianum* provided 66.64 per cent more disease control over negative control treatment. Application of *Pseudomonas fluorescens* resulted in 42.45 per cent fungal wilt control. Application of Mancozeb @ 75 % WP showed lowest fungal wilt disease control (32.70 per cent) under protected cultivation. The disease control ability observed in *T. harzianum* could be because of its ability to induce resistance, suppression of pathogens by production of antibiotics. Similar findings were reported by earlier scientist (Srivastava et al 2010, Mwangi et al 2011, Oyetunji and Salami 2011).

Plant growth: There was significant influence on the growth of tomato plants in response to treatment of biocontrol agents

(Table 3). Plant growth in terms of height (105.13 cm), number of leaves (71.12), stem girth (2.55 cm), leaf area (45 cm^2), fresh weight of shoot (740 g), fresh weight of root (110 g), dry weight of shoot (190.26 g) and dry weight of root (22.30 g) were significantly higher in the treatment of *Trichoderma harzianum*. Followed by *Pseudomonas fluorescens*. The Mancozeb 75% WP treatment plants although superior over control showed significantly lower plant growth characters. Plant growth parameters revealed that soil application of *Trichoderma harzianum* (talc based formulation) was most effective treatment. The better

performance of plants to antagonists' inoculation perhaps be due to the production of growth promoters along with increased microbial activity and biocontrol of fusarium wilt increased growth parameters in plants *viz*. plant height and yield of plant (Narayan et al 2017). Application of *Trichoderma harzianum* may have influenced in efficient uptake of micro nutrients that could also have contributed for better growth of plant, throughout the crop growth period along with the improvement in soil physical and chemical properties which might have resulted in increased leaf area as reported by Baset et al (2010).

Fruit yield: The yield parameters such as number of fruits and yield per plant were significantly high in *Trichoderma harzianum* treated plants (Table 4). Maximum number of fruits (16), fruit yield per plant (1.89 kg) and average fruit weight (96.40 g) were in *Trichoderma harzianum* treated plants. *P. fluresceins* although on par with *Trichoderma harzianum* treated plants but yields d were on the lower side . These two treatments are significantly superior over chemical and control treatments. Similar increase in fruit yield due to application of *Trichoderma harzianum* was reported by Nirmalkar et al (2018) in brinjal. The higher fresh weight and dry weight of shoot and root per plant due to biocontrol agents were also observed by Cornejo et al (2009) and by Lamour et al (2012) in tomato

Table 1. *In vitro* efficacy of bio-control agents against *Fusarium oxysporum* f. sp. *lycopirsici* (*Fusarium* wilt of tomato)

Treatments	Mean growth of mycelium (mm)	Inhibition in mycelial growth (%)
Trichoderma asperellum	52.12	42.08
Trichoderma harzianum	45.12	49.86
Bacillus sp.	47.00	39.11
Pseudomonas fluorescens	56.60	47.78
Mancozeb 75% WP	46.00	37.00
Control	90.00	-
CD (p=0.05)	1.62	1.80

Table 2. Effect of bio control agents on incidence and control of *Fusarium* wilt of tomato under poly house condition

Treatments	Disease incidence (%)	Disease control (%)
T1-Sick soil + *Trichoderma asperellum*	39.60	37.76
T2-Sick soil + *Trichoderma harzianum*	25.43	66.64
T3-Sick soil + *Bacillus* sp.	44.32	33.65
T4-Sick soil + *Psuedomonas florescens*	35.67	42.45
T5-Sick soil + Mancozeb 75 % WP	31.64	32.71
T6-Sick soil (Control)	65.23	0.00
CD (p=0.05)	1.69	1.21

Table 4. Effect of biocontrol agents on yield of tomato under poly house conditions

Treatments	Fruits per plant (No.)	Yield per plant (kg)	Average fruit weight per plant (g)
T1	12	1.31	76.30
T2	16	1.89	96.40
T3.	11	1.14	73.41
T4	13	1.61	85.61
T5	10	0.90	71.50
T6	8	0.81	56.41
CD (p=0.05)	1.29	0.36	18.87

See Table 2 for details

Table 3. Effect of biocontrol agents on growth parameters at harvest (PDI) of tomato

Treatments	Plant height (cm)	Leaves per plant (No.)	Main stem girth (cm)	Leaf area (cm^2)	Fresh weight of shoot (g)	Fresh weight of root (g)	Dry weight of shoot (g)	Dry weight of roots (g)
T1	85.25	58.93	1.68	35	600	90	176.71	17.41
T2	105.13	71.12	2.55	45	740	110	190.26	22.30
T3.	79.71	54.62	1.56	31	570	70	167.50	15.61
T4	96.11	67.87	2.31	40.50	700	110	183.60	20.23
T5	73.08	53.10	1.45	29	540	70	160.41	14.38
T6	56.96	46.35	1.33	23	410	60	128.53	11.61
CD (p=0.05)	5.72	2.18	0.24	0.75	12.02	1.92	3.54	0.77

See Table 2 for details

CONCLUSION

The fusarium wilt incidence can be effectively controlled by treating the plants with fungal biocontrol agent, *Trichoderma harzianum* and bacterial biocontrol agent, *Pseudomonas florescens.* Growth parameters of tomato *viz.* Plant height, number of leaves, stem girth, leaf area, fresh and dry weights of shoot and root as well as yield parameters, fruit yield and number had enhanced in response to biocontrol agents inoculation.

AUTHORS CONTRIBUTION

Sayed Farooq Mahboobi conducted the laboratory and field experiments. T.H. Shankarappa did conceptualization of the experiment and analysis. V. Devappa provided the technical and laboratory facilities. R. Manjunath supervised the work and J.S. Aravind Kumar reviewed the work and manuscript.

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Progeny Evaluation of *Azadirachta indica* (Neem) for Morphometric and Quality Traits under Nursery Conditions

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Abstract: The present study aimed to assess genetic variations for morphometric traits in *Azadirachta indica* progenies under subtropical climatic conditions of Punjab conditions. The seed sources collected across the Punjab were evaluated for seed traits, germination behaviour, growth and biomass traits. Seeds collected from the IGMRI and Parker House mother trees planted at PAU Ludhiana had the maximum seed weight (14.40g/100 seeds) and seed kernel oil content (44.84%), respectively. However, azadirachtin content was maximum in the seeds collected from mother trees planted in south-western districts of Punjab lies in semi-arid region i.e. Bathinda (1.26%), Fazilka (1.25%) and Mansa (1.21%).Seed germination ranged from 6 to 32 days with 17.98 mean germination days and ~72.00% germination success. The maximum germination percent was of IGMRI, PAU Ludhiana (96.66%) followed by Mansa (90.00%) sources. The maximum seedling height (69.11 cm) and collar diameter (1.28 mm) was observed S10 (Barnala progeny) and S7 (BISA, PAU Ludhiana progeny). The maximum root length, number of roots, fresh and dry weight was noticed in seedlings of Raikot progeny; (49.83 cm).The average sturdiness quotient was 36.99 for neem seedlings. Hence the integration of these progenies in the neem improvement programme would result in better field performance for high growth and azadirachtin content.

Keywords: Neem, *Azadirachta indica*, Punjab, Seed source, Seed traits growth and biomass

Neem, botanically called as *Azadirachta indica* A. Juss, belongs to mahagony family Meliaceaeand has two varieties, *A. indica*, believed to be -indigenous of Myanmar and possibly to Shivalik's, Deccan plateau and other parts of South India (Brandis 1906) and *A. excelsa*, reportedly indigenous to South-East Asia. Morphologically anatomically, genus *Azadirachta* and *Melia* appear closely related (Mohanram and Nair 1996). There are acknowledged to be two different varieties of neem; *Azadirachta indica* (Indian neem) and *Azadirachta indica* var. *siamensis* (Thai neem). Indian neem is widely distributed over the Indian sub-continent, while Thai neem is a naturally distributed widely in Thailand and neighbouring nations in South East -Asia (Willan *et al* 1990). In Indian sub-continent, Indian neem is a highly revered by the local people of the region. There are 50 genera and nearly 640 species of woody plants in the Meliaceae family. According to morphology, members of the genus *Melia* are sometimes confused with species of the genus *Azadirachta indica*. However, an easy and precise distinction can be made between the two genera based on the morphology of leaf and ovary.

Creating large scale plantation and as a consequence related to pharmaceutical industry based raw material can be established thus tree can contribute to rural development and economic welfare (Kumar and Mishra 2009). Neem is therefore a priority species for reforestation and for producing a variety of products. In nurseries, seeds are the typically used to propagate trees. However, the seeds are said to have a short viability which is the main issue with employing neem in agroforestry and reforestation programme. Neem trees are found over a wide variety of agro-ecological habitats in India and its neighbouring nations exhibit significant differences in morphological (such as seed weight, leaf form, and phenology) and biochemical (such as there have been reports on azadirachtin and kernel oil content. The real differences in these characteristics that can relate to the variation in the progenies or to adaptation of same genotypes to the various ecosystems where it grows. It is well established that many tree species with a range of geographical diversity exhibit morphological, biochemical and genetic variations as an adaptation to varying environmental conditions (Knothe 2005)

Seed dimensions and weight are variable character with genotype and it is influenced by hereditary, developmental stage and environmental factors (Schmidit 2000). These seed characters influence the dispersal, seed water relations, germination, establishment, survival and growth of seedlings (Wunderle 1997). The life time of seeds is determined by genetic and physiological variables, as well as the storage of environment (Coronado et al 2007). For quality

germplasm, the pattern of inter and intra specific variation, genetic variability among the local germplasm needs to be investigated and analysed. In fact, trees like neem have got less attention to any genetic improvement efforts and, therefore, are considered to possess greater variability compared to other plants. It is important to emphasise the species variety and intraspecific variability that are common in the natural world. Neem's morphological and phenological variants have been the subject of numerous researches (Remedio 2014), but little is known about the genetic foundation of these variations under subtropical climatic conditions of Punjab conditions. Keeping in view, the above-mentioned facts and discrepancies, the present study had been planned to assess the genetic diversity in neem for morphometric characteristics at nursery stage under Punjab climatic conditions.

MATERIAL AND METHODS

The experiment was conducted at, Punjab Agricultural University, Ludhiana, Punjab since 2022-2023. The experimental area falls under the broad region having tropical to sub-tropical climate. The experimental site is located at 30°-54°N latitude and 75°-48° E longitude, 247 m above mean sea level with prolong dry season, high humid spell followed by coldest winters. May and June are considered as the hottest months with intense evapo-transpiration during which hot desiccating winds blow throughout the day. The rainy season occurs from July-to September when the region receives majority share of annual rainfall. December and January are the coldest months when occasional ground frost occurs in the plains. A few light showers during the winters may be received from the North-western depressions arising in the Mediterranean Sea. The site receives on an average 760 mm of rainfall throughout the year which is unevenly distributed and near about 75-80 % of which is showered between the months of July to September. The texture of the soil is sandy loam to clayey with normal reaction. Generally, the soil of the central plain region of Punjab state is identified as alluvial which has a slight problem of alkalinity and salinity. The=soil of the experimental zone has evolved under semi-arid conditions.

Extensive survey was carried out across the Punjab state to select the superior trees at PAU regional stations, KVKs and roadside plantations of state forest department on the basis of high seed-bearing potential and canopy cover for two consecutive years, i.e. 2020-21 and 2021-22. Completely ripen fruits were collected from these marked trees in June-July, 2022 (Table 1). Fruits were de-pulped immediately after collection and placed on cemented floor for sun drying process. Completely dried seeds were further used for data

recording of seed characteristics. Seed dimension, seed weight, seed kernel oil and azadirachtin content were measured in the depulped seeds.

The progeny evaluation experiment of these seed sources was established in three replications with plot size of 50 seeds per plus tree following Completely Randomised Design.Fully mature and depulped seeds were sown about 1 inch deep in 7×5 inches white poly bags containing the mixture of sand, soil and FYM @ 1:1:1 in second fortnight of July. The germination characteristics were recorded on daily basis till the germination of last seed achieved. Normal irrigation and weeding practices were done as per the requirements. Growth traits were recorded at 30, 60, 90, 120 days after sowing while, root, biomass and seedling quality traits were recorded at the end of experiment i.e. 120 DAS.The experimental data were analyzedusing SPSS statistics *version* 21.

Table 1. Details of seed sources of *Azadirachta indica* selected from Punjab state

Code	Location	Latitude	Longitude
S1	Hatchery, PAU Ludhiana	30°54'10.16"	75°48'43.83"
S2	IGMRI, PAU Ludhiana	30°54'24.81"	75°49'00.48"
S3	Fazilka	31°64'18.66"	75°96'21.15"
S4	KVK Abohar	30°09'06.25"	74°13'38.61"
S5	Printing Press, PAU Ludhiana	30°54'13.68"	75°48'34.89"
S6	Rampura, Bathinda	30°15'28.82"	75°11'24.88"
S7	BISA, PAU Ludhiana	30°54'13.26"	75°48'44.62"
S8	Ralla, Mansa	30°06'10.06"	75°26'10.62"
S9	Mahal Kalan, Raikot	30°31'08.04"	75°34'04.81"
S10	Dera Gagiana, Barnala	30°19'14.72"	75°30'07.52"
S11	Bhikhi, Mansa	30°00'15.54"	75°33'44.54"
S12	KVK, Mansa	30°00'05.80"	75°20'40.12"
S13	Rurke Kalan, Barnala	30°14'47.69"	75°26'31.13"
S14	KVK, Mohali	30°51'02.99"	76°43'0.614"
S15	CIPHET, Ludhiana	30°54'14.88"	75°49'00.48"
S16	Type 10/111	30°54'24.81"	75°49'00.81"
S17	Jodhpur farm RRS, Bathinda	30°09'52.23"	74°55'23.25"
S18	KVK, Nurmahal	31°05'50.39"	75°34'58.98"
S19	Jagraon	30°48'40.42"	75°35'58.48"
S20	Dagru, Moga	30°48'59.25"	75°10'18.14"
S21	Parker House, PAU Ludhiana	30°54'08.87"	75°48'59.50"
S22	KVK, Muktsar	30°26'43.59"	74°30'30.01"
S23	Gurudwara Bodh Singh Wala	30°45'19.61"	75°10'21.68"
S24	RRS, Ballowal	31°05'59.02"	76°23'14.43"
S25	RRS, Fardikot	30°40'32.24"	74°44'57.39"
S26	KVK, Firozpur	30°54'35.85"	74°39'46.66"

RESULTS AND DISCUSSION

Seed characteristics: The significant differences were observed in physical parameter like seed length (cm), seed diameter (mm) and seed weight (g/100 seeds) among progenies of neem seed sources (Table 2). The average seed length was 1.23 mm in *Azadirachta indica* seed sources. Seed source S19 (1.62 mm) had the maximum seed length followed by S2 (1.49 mm) source. Source S20 (0.93 mm) had the minimum seed length. The average seed diameter was 6.73 mm recorded for the *A. indica* seed sources. Maximum seed diameter was observed in seed source of S26 (7.56 mm) followed by seeds source of S21 while minimum (5.91 mm) was in seeds of S24 source. The average seed weight was recorded for the *A. indica* seed sources. The average weight of 100 seeds was 9.78 g. The maximum seed weight was in the S2 while, minimum was noticed in S13 source.

Significant differences were also observed for seed kernel oil (%) and azadirachtin content (%) in the kernel of neem seed collected from the selected plus trees marked at various agro-climatic regions of Punjab (Table 2). The average seed oil content was 35.30% recorded for the *A. indica* seed sources. Source S21 (44.84%) had the highest seed oil percent and source S22 (6.06%) had the minimum seed oil percent. The average azadirachtin content in seed kernel was 0.81% recorded for the *A. indica* seed sources. Source S17 (1.26%) had the highest azadirachtin content followed by S3 source and S14 (0.55%) had the minimum azadirachtin content. It was observed that the higher azadirachtin content was observed in the semi-arid districts of Punjab like Bathinda, Mansa and Fazilka. The azadirachtin content was gradually decreased towards the central plain and north eastern districts of Punjab state. However, progeny source S2 planted at PAU Ludhiana had also high

Table 2. Variations in seed morphological and chemical traits in *Azadirachta indica* seed sources

Seed source	Seed length (cm)	Seed diameter (mm)	100 Seed weight (g)	Oil content (%) in kernels	Azadirachtin content (%)
S1	1.29	7.39	9.27	43.87	0.92
S2	1.49	6.91	14.40	35.03	1.12
S3	1.27	6.21	8.48	36.03	1.25
S4	1.19	6.23	9.69	34.49	0.81
S5	1.22	6.71	9.71	28.47	0.81
S6	1.19	6.83	7.99	38.07	0.66
S7	1.19	6.38	11.11	35.40	0.84
S8	1.17	7.18	11.25	28.70	1.21
S9	1.11	7.12	9.18	31.10	0.88
S10	1.18	6.88	7.88	39.96	0.81
S11	1.19	6.28	9.92	32.70	0.82
S12	1.23	6.60	11.21	34.50	0.86
S13	1.09	6.75	7.33	38.46	0.68
S14	1.25	6.29	12.69	37.45	0.55
S15	1.31	6.64	7.86	36.23	0.75
S16	1.18	6.00	11.60	39.47	0.86
S17	1.19	6.67	9.80	37.12	1.26
S18	1.34	7.43	11.46	36.23	0.56
S19	1.62	5.98	11.10	38.45	0.87
S20	0.93	6.58	7.88	37.46	0.86
S21	1.20	7.48	9.89	44.84	0.77
S22	1.30	7.27	8.41	36.06	0.82
S23	1.35	6.42	9.26	38.99	0.82
S24	1.04	5.91	7.71	37.51	0.61
S25	1.20	7.27	10.48	31.83	0.80
S26	1.25	7.56	8.53	39.97	0.79
LSD (0.05)	0.16	0.65	0.39	1.49	0.03

azadirachtin content. This clearly showed the effect of climatic regions on azadirachtin content in neem seed kernels.

Germination characteristics: The results pertaining to the seed germination parameters are presented in Table 3. Data on days taken to first germination showed that seed source did not differ significantly. The minimum day taken for first germination was in S2 source (6.00days), while maximum days were taken by S19 seed source (9.50days) for first germination followed by seed source of S15 (Table 3). The minimum day taken for last seed germination was 17 days in S20 seed source and maximum period was 32days in S2 seed source followed by S3 seed source. Significantly higher mean germination time (17.98%) was in S13 seed followed by S10. The minimum mean germination time was for S18

seed source (12.06%).The mean daily germination varied significantly among *A. indica* seed sources. The significantly higher mean daily germination (2.28%) was in of S2 source followed by S9 source, while, the minimum mean daily germination was for S20 (0.59%). The mean germination rate (0.06%) varied significantly among *A. indica* seed sources. The significantly higher mean germination rate (0.07%) was noticed in S1 seed followed by S3. The minimum mean germination rate (0.06%) was observed for different seed source like S6, S7,S8, S9, S12 and S13.

Significant differences were recorded for germination percentage of progenies of neem seed source (Table 3). The average value of germination percentage was 72%for*A.indica* seed sources. *Azadirachta indica* seeds attained maximum germination percentage by S2 seed

Table 3. Variabilities in seed germination characteristics of *Azadirachta indica* seed sources

Seed source	Days taken for first germination	Days taken for last germination	Mean germination time (Day)	Mean daily germination percent (%)	Mean germination rate (Day^{-1})	Germination percent (%)	Germination energy (%)	Germination value	Germination index (day)	Peak value for germination (Day^{-1})
S1	8.00	31.99	13.82	1.65	0.72	81.00	2.80	9.37	6.81	3.24
S2	6.00	32.00	14.53	2.28	0.69	96.66	3.95	9.72	7.63	3.03
S3	8.00	32.00	14.02	1.69	0.72	81.00	2.83	8.17	6.53	2.82
S4	8.00	30.99	15.03	1.32	0.66	85.00	2.27	8.44	6.45	2.78
S5	6.99	29.00	14.57	1.72	0.07	80.00	3.09	7.46	5.97	2.60
S6	8.00	30.00	16.96	1.48	0.06	78.00	2.67	7.31	6.07	2.62
S7	7.63	29.00	16.82	1.38	0.06	78.00	2.51	7.23	5.96	2.59
S8	6.83	30.00	16.24	1.39	0.06	80.66	2.56	7.31	5.94	2.53
S9	6.27	28.99	16.90	2.06	0.06	80.00	3.72	7.36	6.04	2.55
S10	7.36	29.00	17.47	1.75	0.06	77.00	3.04	6.37	5.31	2.31
S11	7.60	30.00	16.41	1.31	0.06	90.00	2.40	14.81	6.91	3.97
S12	7.37	28.00	16.64	1.64	0.06	65.33	3.34	5.30	5.07	2.23
S13	7.61	28.00	17.98	1.48	0.06	63.66	2.77	4.73	4.63	2.03
S14	7.86	26.20	16.88	1.34	0.06	69.33	2.58	5.52	5.07	2.16
S15	9.29	29.00	16.60	1.07	0.06	74.33	2.03	6.65	5.60	2.44
S16	6.94	27.00	16.98	1.26	0.06	71.33	2.47	6.01	5.18	2.31
S17	8.94	26.99	14.56	1.27	0.07	75.33	2.25	6.50	5.53	2.41
S18	7.80	18.00	12.06	0.66	0.08	65.33	1.70	5.05	4.73	2.12
S19	9.50	19.00	12.41	0.70	0.08	59.33	1.81	3.92	4.27	1.83
S20	8.06	17.00	11.68	0.59	0.08	71.00	1.56	5.52	5.20	2.15
S21	7.00	18.99	12.31	0.62	0.08	75.00	1.60	6.25	5.21	2.30
S22	7.98	20.00	12.99	0.75	0.08	72.00	1.84	5.53	4.70	2.15
S23	8.00	18.00	11.69	0.72	0.09	67.66	1.93	5.27	4.97	2.17
S24	7.00	19.00	12.62	0.72	0.07	73.00	1.83	5.77	4.90	2.21
S25	7.00	18.99	11.50	0.66	0.08	69.33	1.83	5.47	4.82	2.14
S26	9.00	20.00	13.33	0.66	0.07	78.33	1.59	7.19	5.68	2.52
LSD (0.05)	NS	1.12	0.56	0.27	0.01	16.07	0.50	4.46	1.39	0.87

source (96.66%) which is followed by S11 seed source (90.00%). The minimum germination percentage was obtained in seeds of S19 source (59.33%). The average value for germination energy was 2.43%. The significantly higher germination value (3.95) was in S2 seed source followed by S9 source while, the minimum germination energy was (1.56) in S20 source. The mean germination value was (6.85) for *A. indica* seed sources. The maximum germination was 14.81 for S11 seed source followed by S2. The minimum germination was in S19 (3.92). The mean germination index was (7.53) day for *A. indica* seed sources. The maximum germination index was for S2 (7.63) followed by S11. The minimum mean germination index was in S19 (4.27). The average peak for germination was 2.28 day^{-1} for *A. indica* seed sources. It was also apparent from the data that significantly higher peak value for germination (3.97) was in

S11 seeds source followed by S1 seed source while, the minimum was in S19 seed source (1.83%). Light, as an environmental signal, often plays an important role in promoting seed germination (Mayer and Poljakoff-Mayber 1989). Higher germination percentage, germination energy and germination value conditions may be due to effect of full light, optimum temperature and micro-climate factors, which promote germination. Irengbam and Thapliyal (2016) reported significant variability among ten seed sources of *Bauhinia purpurea* with respect to germination per cent, seedling growth and vigour.

Growth, biomass and quality characteristics: The significant differences were observed for the seedling height and collar diameter among *Azadirachta indica* progenies under nursery conditions and increased progressively with increase in the age of seedlings (Table 4). Significantly

Table 4. Seedling height and diameter growth among *Azadirachta indica* seed sources with respect to time

Seed sources	Seedling height (cm)			Seedling collar diameter (mm)		
	30 DAS	60 DAS	120 DAS	30 DAS	60 DAS	120 DAS
S1	18.77	21.33	29.45	0.94	1.04	1.37
S2	47.15	50.12	60.12	0.73	0.89	0.98
S3	13.04	19.12	32.14	0.82	0.91	1.03
S4	41.47	51.22	68.44	0.63	0.85	1.08
S5	45.25	49.22	67.74	0.79	0.80	0.86
S6	15.10	23.44	36.11	0.81	0.83	0.97
S7	13.81	22.77	37.44	1.16	1.17	1.28
S8	18.77	26.74	39.12	0.96	1.05	1.12
S9	39.31	45.12	56.12	0.87	0.88	1.17
S10	45.17	52.31	69.11	0.36	0.52	0.85
S11	37.64	49.31	62.14	0.25	0.30	0.49
S12	32.84	37.15	48.57	0.47	0.50	0.76
S13	31.56	38.14	52.11	0.33	0.37	0.65
S14	16.51	23.41	35.14	0.18	0.20	0.31
S15	38.05	48.12	62.14	0.74	0.87	0.94
S16	25.54	32.14	49.57	0.84	0.89	0.98
S17	35.34	42.32	56.41	1.02	1.05	1.21
S18	42.64	47.15	56.14	0.70	0.77	0.91
S19	29.08	35.12	49.26	0.23	0.35	0.44
S20	15.80	22.33	43.21	0.70	0.75	0.78
S21	39.31	49.12	63.14	0.53	0.54	0.67
S22	13.04	23.14	46.14	0.70	0.77	0.97
S23	24.33	31.14	50.14	0.60	0.66	0.76
S24	15.35	23.45	46.14	0.66	0.69	0.81
S25	12.24	19.14	36.47	0.97	1.04	1.11
S26	26.04	34.21	55.45	0.61	0.71	0.82
LSD (0.05)	9.68	10.31	11.01	0.279	0.316	0.496

maximum seedling height was in seed source S2(47.15 cm), S10 (52.31 cm) and S10 (69.11 cm), while minimum wasin S25 (12.24 cm), S3 (19.12 cm) and S1 (29.45 cm) at 30 , 60and 120 DAS, respectively. The mean collar diameter wasin S7 .Plant height and collar diameter are widely used to assess the quality of nursery seedlings (Jacob *et al* 2005*).* Similarly, Gera *et al* (2003) while working with *Acacia catechu, Albizia lebbeck*, *A. indica* and *Pinus roxburghii* observed maximum plant height, collar diameter and other seedling growth parameters with improved bottom hole poly bag production system for nursery production. Prabakaran et al (2019) also recorded significant variations for growth and biomass traits in *A. indica* progenies grown under tropical environment.

Approximately, 120 days after seed sowing, the seedlings were uprooted for the biomass studies. Scrutiny of the data presented in depicts that the significant differences were observed for root length. Maximum value for root length was for S9 (49.83 mm) and minimum was in S26 (19.20 mm) (Table 5). Maximum value for numbers of root was in S5 (1.83) while, the minimum value was in S26 (0.80). The maximum total fresh weigh (4.58 g/plant) was in S3 at 120 days of sowing. The minimum value for total fresh weight was in S26 (1.08 g/plant).The maximum total dry weight of neem seedling was 1.83 g/plant in S3 seed source at120 days of sowing. The minimum total dry weight of neem seedling was 0.11 g/plant in S26.The average sturdiness quotient was 36.99 for *A. indica* seed sources (Table 5). The significantly maximum value of sturdiness quotient was 77.57 for S23 followed by S24 source. The minimum was 17.260 for S14 seed source.

Table 5. Variability among root growth, seedling biomass and seedling quality characteristics of *Azadirachta indica* seed sources

Seed source	Root length (cm)	Number of roots	Seedling fresh weight (g/plant)	Seedling dry weight (g/plant)	Sturdiness quotient
S1	45.33	1.50	2.75	1.50	45.70
S2	42.67	1.66	2.75	1.08	60.80
S3	19.63	1.16	4.58	1.83	54.07
S4	31.33	1.33	4.43	1.00	49.03
S5	43.50	1.83	3.25	1.66	63.90
S6	29.67	1.16	2.33	1.08	41.87
S7	45.17	1.00	2.41	1.25	38.47
S8	44.17	1.50	3.25	1.50	56.20
S9	49.83	1.66	3.08	0.83	45.13
S10	38.83	1.50	2.75	1.25	21.36
S11	36.67	1.00	3.16	0.75	50.50
S12	42.17	1.66	2.83	1.25	46.40
S13	28.67	1.50	3.33	1.16	57.10
S14	40.50	1.66	3.91	1.50	17.26
S15	40.50	1.00	3.83	1.08	54.87
S16	37.67	1.33	2.75	1.25	51.97
S17	31.67	1.33	3.16	1.33	42.17
S18	33.00	1.16	2.08	1.00	36.03
S19	40.00	1.33	1.83	0.75	40.13
S20	33.67	1.33	2.08	1.25	63.17
S21	30.00	1.50	1.66	0.75	35.53
S22	37.33	1.50	2.16	0.66	48.47
S23	34.67	1.33	1.83	0.91	77.57
S24	32.00	1.16	1.58	1.08	66.73
S25	31.00	1.00	1.83	0.91	45.97
S26	19.20	1.00	1.08	0.11	28.03
LSD (0.05)	12.988	NS	1.588	0.637	42.89

The significant differences were obtained among the seed sources and seedling height and collar diameters is continuously increases with the increasing age of seedling. Wide variations were recorded for growth and biomass traits among seed sources in these studies., Ginwal et al (2004) reported significant differences among the seed sources of *Eucalyptus camaldulensis* at the nursery stage for number of leaves as well as collar diameter. Hooda et al (2009) observed significant variations among the progenies for shoot length, root length, collar diameter and seedling biomass of *Pongamia pinnata*. Therefore, these variations were suggested for exploitation for indirect selection as a mechanism for the genetic enrichment of the tree's species.

Genetic estimates: In general, the phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) for all characters reflecting the sufficient genetic variations for the characters studied among progenies of neem seed sources (Table 6). Genotypic coefficient of variance was observed in seedling height exhibit maximum GCV (23.86%) followed by fresh biomass, dry biomass and root length. In phenotypic coefficient of variance, seedling fresh biomass (40.04%) exhibit maximum value for PCV followed by number of roots and dry biomass.

The seedling height (99.01%) exhibited the very high heritability which is followed by collar diameter. Fresh biomass (32.34%), root length (30.38%) and dry biomass (26.68%) had moderate heritability, while, number of roots (3.85%) exhibited lowest heritability. Highest value for genetic advance was exhibited by seedling height (23.35) and least in numbers of roots (0.05). In genetic advance as percentage of mean, maximum value was observed for seedling height (48.92) followed by fresh biomass (26.68), and least value was observed by numbers of roots (3.05). The high heritability indicated that much of the variation for a given characteristic observed in the population was genetic in origin. High heritability (>60%) coupled with high genetic gain observed for seedling height which revealed that the traits was under the strong influence of additive gene action and selection would be quite effective.

Correlation studies: The phenotypic (Table 7) and genotypic (Table 8) correlations were estimated to assess the relationship among the traits in progenies of neem seed sources. In genotypic correlation, high positive correlation was observed for dry weight and number of roots (0.993) followed by fresh weight and dry weight (0.774), while moderate was in between of collar diameter and number of

Table 6. Estimates of genetic parameters among *Azadirachta indica* seed sources

Parameters	Seedling height	Collar diameter	Fresh biomass	Dry biomass	Root length	Number of roots
Mean	43.82	16.18	24.51	20.79	17.24	10.58
Range	29.45-69.11	0.31-1.37	1.08-4.58	0.11-1.83	19.63-49.83	1.00-1.83
GCV (%)	23.86	4.73	22.77	19.27	14.13	7.55
PCV (%)	23.98	5.98	40.04	37.30	25.64	38.43
Heritability (%)	99.01	62.44	32.34	26.68	30.38	3.85
Genetic advance	23.35	0.09	0.73	0.23	5.85	0.05
Genetic advance as % of mean	48.92	7.70	26.68	20.51	16.05	3.05

Table 7. Genotypic and phenotypic correlations among growth and biomass characteristics in *Azadirachta indica* seed sources

Characters		SH	CD	FW	DW	RL
CD	G	0.169[NS]				
	P	0.147[NS]				
FW	G	0.142[NS]	-0.432**			
	P	0.070[NS]	-0.179[NS]			
DW	G	-0.505**	-0.583**	0.774**		
	P	-0.278*	-0.264*	0.381**		
RL	G	0.089[NS]	-0.079[NS]	-0.062[NS]	0.217[NS]	
	P	0.044[NS]	-0.125[NS]	0.019[NS]	-0.138[NS]	
NoR	G	-0.330**	0.561**	0.247*	0.993**	-0.237*
	P	-0.059[NS]	0.074[NS]	-0.019[NS]	0.061[NS]	-0.106[NS]

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).: SH- seedling height; CD- collar diameter; FW- fresh weight; DW- dry weight; RL- root length and NoR- number of roots

roots (0.561). Negative significant correlations were among seedling height with dry weight and number of roots, collar diameter with fresh weight and dry weight, root length with number of roots. In view of phenotypic correlation, low positive correlation was observed for fresh weight and dry weight, while moderate negative significant correlation was shown by dry weight with seedling height and collar diameter. Remaining characters has no significant correlation.

CONCLUSIONS

There were significant differences among the progenies of neem seed sources which had ample scope for the genetic improvement in neem under subtropical climatic conditions of Punjab. Among the 26 progenies evaluated, seeds collected from south-western districts of Punjab had high azadirachtin content, while seed kernel oil content was higher in PAU Ludhiana source, and could be exploited by the pharmaceutical industries or fertilizer industries for preparation of neem based pesticides and neem coated urea. Germination percent was also higher for the Ludhiana and Mansa seed source. The quality seedlings based on sturdiness quotient were produced by the Moga and Ludhiana seed sources. Hence, huge genetic variabilities were obtained in neem progenies evaluated under nursery conditions and appreciable improvement in seeds traits, germination, growth and biomass parameters can be achieved by collecting seeds from selected plus trees belongs to either Ludhiana or south-western districts on a short-term basis. These seed sources show promise in their further exploitation for plantation, improvement, and multiplication under field conditions.

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Field Evaluation of Different Weeders in Cauliflower Cultivation of Muzaffarpur District in Northern Bihar, India

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Abstract: Field experiment was conducted to evaluate the performance of different weeders namely Khurpi, improved Grabar, push type twin wheel hoe weeder and power weeder in the cauliflower field of seven farmers during the year 2021-22 and 2022-23. Various parameters such as weeding efficiency, field capacity, plant damage, performance index and economics of weeding operation were observed to assess the performance of different weeders. The power requirement was maximum for power weeder (3 hp) which was also associated with highest effective field capacity (0.05 ha/hr) and plant damage (2.24%). Maximum and minimum weeding efficiency pertained to *khurpi* (98%) and power weeder (81%) respectively. Highest performance index in improved *grabar* (1781.46) followed by push type two-wheel weeder (1546.74). The weeding operational cost was reduced by 50, 40 and 86.25% respectively for improved *grabar*, push type two-wheel weeder and power weeder as compared with *khurpi*. The economic analysis showed that despite of the low yield in power weeder as compare to other treatments, the maximum gain in net return due to lowest cost of cultivation showed that power weeder economically more feasible, viable and acceptable to the farmers.

Keywords: Field capacity, Performance index, Weeder, Weeding efficiency

Bihar is the third largest producer of cauliflower in the country and shares nearly 10.86% of the total production. An area of 65.71 thousand hectares is under cauliflower cultivation in Bihar and produces about 935.56 thousand tonnes of cauliflower annually with an average productivity of about 15.28 tonnes per hectare. Cauliflower is a very sensitive crop to various stresses including weeds which needs more care to grow successfully than most of other vegetables. Weeding is a time consuming and labour-intensive intercultural practice in the agriculture which accounts for about 25 % (900-1200 man-hours/hectare) of the total labour requirement (Yadav and Pund 2007). In India due to weed infestation an annual loss projected about 82 million tons in food grains, 14 million tons in pulse, 12 million tons in oil seeds and about 52 million tons in commercial crops (Singh 2013). Presently various types of weeders are developed in India are helpful for weeding in agriculture. The most common methods of weed control are mechanical, chemical, biological and traditional methods. Among them, mechanical weeding either by hand tools or weeders are most effective (Manjunatha et al 2014). Manually operated weeders have found wide acceptability due to their low cost (Behera and Swain 2005). Weed control and weeding work is mainly done by majority of farm women in India by using small hand tools like *khurpi*. Weeding through *khurpi* is most efficient way to reduce weeds but is labour intensive and very costly. Therefore, it is necessary to evaluate the

performance of various types of manual as well as mechanical weeder. The present study is focussed to access the field performance of different weeders in term of economics, drudgery and farmers friendly to save farmers from drudgery, stress and minimising the cost of cultivationin cauliflower.

MATERIAL AND METHODS

The present study was carried out in seven farmers field located at Sakra and Muraul block of Muzaffarpur district during the year 2021-22 and 2022-23. The experimental site geographically lies between latitude 25°51'10" to 26°01'30"N and longitude 85°23'10" to 85°39'00"E (Table 1). All the seven location of experimental site falls under Northern West Agro-climatic Zone I location predominant in sandy loam soil with the total average annual rainfall of 1250 mm. The average temperature at all locations during the entire cropping season for the year 2021-22 and 2022-23 was 19.5^{0}C and 20^{0}C respectively whereas, average rainfall was recorded as 80.2 mm (2021-22) and 12.86 mm (2022-23). Monthly average temperature and rainfall of both the year are presented in Figure 1.

The cauliflower seedlings 20 days old with 15 cm height were transplanted manually at 45x30 cm spacing at seven different locations in two consecutive year 2021-22 and 2022-23.Cauliflower crop is ready to harvest in 90-120 days after transplanting (DAT). Weeding practices were carried

out three times at 30, 45 and 60 DAT. Major weed infestation comprises of *Chenopodium album* a broad leaf weed locally called Bathua and *Phalaris minor* a narrow leaf weed was observed at all the locations. Across the location the weed population at 30, 45 and 60 DAT respectively was observed as 90.3, 124.7 and 190.6 per square metre. Data observation on draft, speed of operation, power requirement, effective field capacity, field efficiency, plant damage, weeding efficiency and performance index were recorded from the randomly selected area of $1m^2$ in each field to access the weeding impact of different weeders. Weeding cost (Rs.), crop yield (q/ha) and total cost of cultivation (Rs.) were also accessed to calculate the economics and B:C ratio of the crop produced.

Performance Test

Draft force: Draft force important to push or draw the implement for weeding task. For physically operated soil working instruments the draft should be inside the physiological limit of the operator. The draft force of weeder can be determined by the following formula as per the Yadav and Pund (2007).

$D = W \times d_w \times S_R$

Where, D = Draft power of the weeder (N), d_w = depth of cut (cm), W = width of cut (cm), S_R = particular soil opposition (N cm^{-2}).

Speed of operation (km/h): Speed of operation of wheel operated sprayer cum weeder was measured the time required to cover 8m distance. Speed was calculated as

Table 1. GPS location of all the sites at Sakra and Muraul block of Muzaffarpur, Bihar

Name of village	Name of block	Latitude (N)	Longitude (E)
Machhahi	Sakra	25^{0}57'32"	85^{0}33'33"
Keshopur	Sakra	25^{0}56'58"	85^{0}34'28"
Muramohanpur	Sakra	25^{0}58'28"	85^{0}33'59"
Sujawalpur	Sakra	25^{0}57'28"	85^{0}33'48"
Dholi	Muraul	25^{0}59'53"	85^{0}35'14"
Lautan	Muraul	25^{0}59'23"	85^{0}35'33"
Itha	Muraul	25^{0}58'44"	85^{0}36'04"
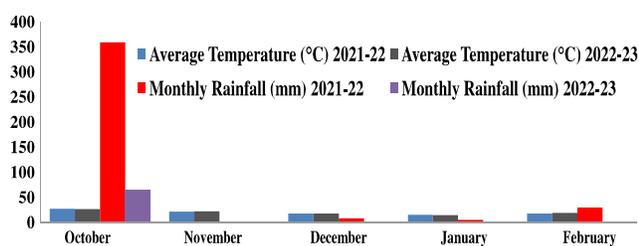
Fig. 1. Monthly Average temperature and rainfall for the year 2021-22 and 2022-23

follows (RNAM Procedure 1995).

$$\text{Speed (kmph)} = \frac{3.6 \times \text{distance travelled (m)}}{\text{time (s)}}$$

Power requirement (hp): Calculation of power is needed to determine the efficient use of man power. A man can produce power equal to 0.05 to 0.1 hp operated for day long work. It was the power requirement to the implement by the man with average pushing force and speed (Michael and Ojha 1966).

$$\text{Power (hp)} = \frac{\text{Draft (kg)} \times \text{Speed (m/s)}}{75}$$

Effective field capacity (ha/h): This is the actual field capacity of weeder and was calculated as

$$\text{Effective field capacity (ha h}^{-1}) = \frac{A}{T_1 - T_2}$$

Where, A = actual area covered, ha T_1 = Total time require for operation in hours T_2 = non-productive time in hours.

Field efficiency (%): It was calculated by using the formula suggested by Dubey (2001).

$$\text{Field efficiency, n} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100$$

Plant damage (%): Plant damage percentage is measured using the following equation (Yadav and Pund 2007).

PD = [1 − qp] × 100

Where PD = plant damage, q = number of plants in a 10 m row length after weeding, p = number of plants in a 10 m row length before weeding.

Weeding efficiency (%): The number of weeds present in one m^2 area before and after weeding operation was counted by the equation given below (Remesan et al 2007).

$$WE = \frac{N_1 - N_2}{N_1} \times 100$$

Where, WE= Weeding efficiency, (%) N_1 = Number of weeds/m^2 before weeding N_2 = Number of weeds/m^2 after weeding

Higher value of WE shows the weeder is more efficient to remove the weeds.

Performance index: Weeder performance assessed through performance index was computed (Gupta 1981).

$$P.I = \frac{FCX (100 - PD) \times WE}{P}$$

Where, FC= Field capacity of the weeder, ha h^{-1}, PD = Plant damage (%), WE = Weeding efficiency (%) and P = Power input in hp

RESULTS AND DISCUSSION

There was substantial effect of weed management practices on all the growth parameters as well as yield. Although, the power requirement of power weeder was highest (3hp) but its incorporation in weeding can reduce

Table 2. Effect of technology option on power requirement, effective field capacity, field efficiency, plant damage, weeding efficiency and performance index

Parameters/ Treatment	Power requirement (hp)	Effective field capacity (ha/hr)	Field efficiency (%)	Plant damage (%)	Weeding efficiency (%)	Performance Index
T_1	0.05	0.002	91.0	0.24	98	391.06
T_2	0.08	0.016	83.0	1.02	90	1781.64
T_3	0.10	0.018	85.0	1.23	87	1546.74
T_4	3.00	0.05	71.5	2.24	81	131.98

Table 3. Economics of weeding option on yield, cost of cultivation, gross return and BC ratio of cauliflower

Parameters/ Treatment	Cost of weeding implements (Rs.)	Cost of weeding (Rs. /ha, 3 times per crop)	Yield (q/ha)	Cost of cultivation Rs./ha	Gross return Rs./ha	BC ratio
T_1	80	50880	210	100500	252000	2.51
T_2	400	25440	201	77060	241200	3.13
T_3	1200	30528	198	79972	237600	2.97
T_4	48000	6996	192	63956	230400	3.60

drudgery due to its higher field capacity (0.05 ha/h) among all hand tools. Weeding efficiency of T_1 was highest (98%) followed by T_3 and T_2. Shekhar et al (2010) and Kumar et al (2014) also observed the highest weeding efficiency with *khurpi* than the other weeders. The maximum weeding efficiency might be due to capability of this hand tools to work between plant to plant spaces in a row as well as weeding in periphery of root surface area is also possible by this method but other weeders may not be used around root periphery and between the two plants of closely/ densely planted. Highest field capacity (0.05 ha/h) was with power weeder followed by T_3 and T_2. However, the field efficiency was maximum in T_1 (91%) and among the mechanical weeders T_3 (85%) exhibited highest while was minimum in T_4 (71.5%) (Table 2). Shekhar et al (2010) in maize and Ragesh et al (2018) in paddy field observed the same trend. On contrary, highest field efficiency recorded in power weeder as compare to other mechanical weeders in paddy was reported earlier by Narwariya et al (2016). The variable field capacity of different tools/implements depends on the width of soil cutting parts and forward speed. The maximum operational speed and more weeding width of power weeder confer its higher field capacity as compare to other weeding methods. The plant damage recorded at 30, 45 and 60 DAT revealed that maximum damage was in power weeder (2.24%) while was minimum with *khurpi* (0.24%). Plant damage in T_2 and T_3 operations were at par however, was greater than T_1 but less than T_4. Higher rotating speed of blade as well as higher travel speed might be the reason of maximum damage of plant observed in power weeder as compared to other methods. Similar findings reported by Narwariya et al (2016) in paddy field.

Economics and BC ratio of cauliflower was calculated at all the locations and pooled data of both the year presented in Table 3. Cost of cultivation per hectare excluding weeding cost for all the treatments was same which includes nursery bed preparation, seed, pesticides and other chemicals, fertilizers and manure, harvesting cost. The small variation was observed due to miscellaneous cost. Despite of minimum field efficiency as well as weeding efficiency and maximum plant damage as compared to conventional method, mechanical method of weeding was most economical. Gross return was maximum in T_1 but cost of weeding was highest which reduced the net income and hence the least BC ratio (Table 3) but as compare to T_1 decrease of 86.25 % cost of weeding was estimated in T_4 which was due to labour deficit in areas . The T_2 and T_3 showed 50 and 40% reduction in cost of weeding. Conventional method of weeding difficult due to less availability of farm labours at peak season. T_2 and T_3 methods also revealed that without affecting yield significantly highest amount of return can be achieved as BC ratio was 3.13 and 2.97, respectively.

CONCLUSION

The power requirement was maximum for power weeder (3 hp) which was also associated with highest effective field capacity (0.05 ha/hr). The incorporation of power weeder in weeding operation reduced labour cost as well time of operation and there was a decrease in cost of weeding as compare to *khurpi* which was due to less labour requirement resulted in highest BC ratio. Maximum and minimum weeding efficiency was observed in khurpi and power weeder, respectively. Highest performance index recorded in

grabar due to less plant damage in compare to two-wheel weeder and observed lowest in power weeder due to highest plant damage. Therefore, utilization of power weeder and other manually operated weeder as compare to hand weeding can increase net income of cauliflower growing farmer.

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Effect of Duckweed as Alternate Protein Source on Rumen Fermentation and Health Status of Beetal Goats

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Abstract: "Duckweed" to refer to members of the aquatic plant family *Lemnaceae*. A duckweed feeding trial was carried out at the Goat Farm of the Department of Livestock Production and Management, GADVASU, Ludhiana with 20 male goats fed four different diets. The objective of the trial was to evaluate the use of duckweed (*Spirodela polyrhiza*) and duckweed-based TMRs and use as a protein supplement for ruminants. The hypothesis was that duckweed is a suitable protein source for goats and will behave in a similar fashion to soybean meal. The diets included a control group (all supplemental protein from soybean meal), 1/3 duckweed, 2/3 duckweed, and 100% duckweed (corresponding to 1/3, 2/3, and 100% of the supplemental protein from duckweed, respectively). The goats were fed equal amounts of fodder and concentrate ration in 50: 50 R:C at 4% of body weight (as fed). Duckweed supplementation in male goats significantly increased blood cholesterol and creatinine levels as compared to the control group, but the values were within the physiological range. Duckweed supplementation did not have any adverse effects on rumen fermentation parameters (pH, TN, NPN, NH_3, TVFA and TCA-pptN). Based on the above results concluded that duckweed can be used as alternate protein source in goats' feeding without any adverse effects.

Keywords: Duckweed (*Spirodela polyrhiza*), Goats, Rumen fermentation, Retention, Blood parameters

Feed cost is most important in animal production systems and chiefly determines the profit margins for the farmer. Dairy producers strive to acquire the most economically efficient sources of nutrients to meet the precise nutrient requirements of the dairy cows. By-products present a cost-effective alternative to traditional feed ingredients. However, before substituting traditional feed ingredients with by-products, several factors such as acceptability, consistency, availability, and quality must be carefully considered. One noteworthy example of such a feedstuff is duckweed, which is a tiny, free-floating, vascular aquatic plant. It has similar crude protein levels and also contains the essential amino acids needed in ruminant rations. Studies have shown that duckweed can have crude protein levels as high as 45%. Moreover, duckweed offers high-quality protein with an amino acid profile similar to most plant proteins, rivalling animal protein sources. When comparing the annual dry matter yield, duckweed excels, producing between 10 to 30 tons per hour (Leng et al 1995), while alfalfa only yields about 11 metric tons per hectare per year. Another advantageous aspect of duckweed is the low lignin content in its cell walls, which contributes to increased fiber digestibility . The entire body of duckweed consists of non-structural, metabolically active tissue, making it remarkably high in nutritional value (FAO 2009).

Despite the potentially beneficial attributes of duckweed on ruminant animal performance, the practice of feeding aquatic plants has received limited attention. This plant may offer a viable alternative to crop production in areas where land is scarce, of poor quality or experiencing inadequate and variable precipitation. Given the future challenge of meeting the global protein demand, the importance of duckweed as an alternative protein source in animal diets is growing significantly. Hence, this research aims to explore the nutritional quality of duckweed, particularly as a protein source, and its effects on rumen fermentation and blood profiles in ruminants.

MATERIAL AND METHODS

The duckweed sample for this study was obtained from the College of Fisheries, GADVASU, Ludhiana. The sun/ air-dried duckweed was ground in a Wiley mill through a 2mm screen. The total mixed rations (TMR) were prepared by incorporating different levels of duckweed, namely control, 1/3 duckweed, 2/3 duckweed, and 100% duckweed, which replaced the total crude protein (CP) derived from soybean in a 50:50 ratio (R:C), as indicated in Table 1. All the TMR prepared were iso-nitrogenous, having approximately 15% CP.

Animal Feeding: Male goats (20; 15kg body weight) were divided into 4 equal groups and were offered with four different total mixed rations i.e. TMR1 (control), TMR2 (1/3

duckweed), TMR3 (2/3 duckweed) and TMR4 (100% duckweed) for a duration of 120 days.

Housing: The male goats were accommodated in a concrete shed and provided with group stall feeding at 9:00 am each day. They were given unrestricted access to water twice a day and were allowed for 1-hour at the yard on a daily basis.

Chemical analysis: Samples of feed, faeces, and orts were subjected to analysis for proximate constituents following the AOAC (2000) guidelines. Cellulose analysis was performed according to Crompton and Maynard (1938), while cell wall constituents were determined following the methodology outlined by Robertson, Van Soest et al (1981).

Rumen liquor analysis: All the male goats were given the respective experimental diets as per the experimental design. Rumen liquor was collected four hours after the experimental feeding. Specialized stomach tubes were used to collect rumen liquor from various sites of the rumen. Subsequently, all the collected rumen liquor samples were pooled based on their respective sampling hours and stored in a refrigerator until analysis. The strained rumen liquor was then analyzed for various parameters, including pH, total volatile fatty acid (using the method described by Cottyn and Boucque in 1968), total nitrogen, TCA-precipitable nitrogen, and ammonia nitrogen, following standard procedures.

Estimation of blood biochemical profile: Blood samples were collected from male goats through the jugular vein both on day 0 and after the experimental feeding. The serum was then stored at -20°C for further analysis of various parameters, including glucose, BUN, cholesterol, GGT, AST, ALT, triglycerides, total protein, and creatinine. Diagnostic kits from Siemens Autopack were used to estimate these biochemical parameters, which were subsequently analysed using the RA-50 blood analyser.

Statistical analysis: The data was analyzed using SPSS Version 19. To assess the differences in means, the Tukey B test was employed.

RESULTS AND DISCUSSION

Rumen fermentation parameters *in vivo*: The pH of the rumen liquor remained unchanged with duckweed supplementation, indicating that it has no adverse effects on rumen microflora. Typically, the normal rumen pH values for ruminants offered mixed rations range from 5.8 to 7.0, depending on factors such as protein content, degradability, carbohydrate quantity and type, roughage characteristics, and roughage to concentrate ratio. In general, the pH level in the rumen liquor shows an inverse correlation with total volatile fatty acid) concentration. The rumen pH did not show a significant difference among the groups supplemented with varying levels of duckweed and the control group (Table 2). Moore et al (2002) observed that in soybean meal (pH 6.52) and soybean hull (pH 6.41) diet, the rumen pH values for in duckweed diet in present study were lower. This discrepancy may be attributed to the fact that our diets consisted of 50% concentrate and 50% fodder, whereas they fed a lower level of concentrate.

The mean ammonia-N concentration (mg/dl SRL) did not show a significant effect (values ranged from 49.52- 59.67, groups I, II respectively). The ammonia-N concentration in this study surpassed the minimum threshold of 5-8 mg/100 ml SRL, as proposed for optimum microbial growth in all four groups. The values were consistently higher than the proposed threshold. During the conversion of dietary nitrogen (N) into microbial protein, NH3 plays a crucial role as an intermediate in the rumen. Consumption of a substantial amount of protein can lead to an excessive production of NH3 in the rumen. If the rate of NH3 production surpasses its utilization by rumen microbes, the concentration of NH3 in

Table 1. Ingredient composition of different concentrate mixtures containing duckweed

Ingredient	Control	1/3 duckweed	2/3 duckweed	100% duckweed
Maize	35	35	35	35
Soybean	28	18.6	9.3	0
Duckweed	0	15.5	31	46
Wheat bran	17	13	8	4
Rice bran	14.75	12.6	11.5	9.5
Mineral Mixture	2	2	2	2
Salt	1	1	1	1
Urea	0	0.3	0.7	1
Bypass fat	2.25	2	1.5	1.5
NFC	26.63	21.43	14.25	15.10

R:C 50:50 (Roughage: concentrate)

the rumen increases. This increase is particularly noticeable when the diet lacks readily available carbohydrates.

The total nitrogen content in strained rumen liquor (SRL) primarily reflects the solubility of ingested protein in the rumen and may also vary depending on the amount of protein intake. In the duckweed supplemented groups (group II, III, and IV), the total nitrogen levels were 239.49, 176.57, and 189.70 mg/dl, respectively. These values did not show a statistically significant difference compared to the control group, where it was 250.07 mg/dl (Table 2). The TCA-ppt N mainly represents microbial nitrogen. The supplementation of 1/3 duckweed resulted in an increase in the concentration of TCA-ppt N (mg/100 ml) in group II, followed by group I, and the lowest increase was observed in the 2/3 supplemented duckweed group.-The TCA-ppt N concentrations (mg/dl) in the rumen liquor were 121.34, 135.38, 79.62, and 99.89 in groups I, II, III, and IV, respectively. The observed increase in TCA-ppt N can be partly attributed to the enhanced utilization of ammonia and feed nitrogen by rumen microorganisms for their body protein synthesis, and partly to an increase in protozoal numbers. The non-protein nitrogen fraction primarily comprises ammonia nitrogen, along with small quantities of amides, amino acids, etc. Consequently, the concentration of non-protein nitrogen in the rumen fluid primarily relies on the production of ammonia, its uptake by microbes, and absorption through the rumen wall. Additionally, the non-protein nitrogen concentration (mg/100ml SRL) was lower in group IV (89.81) and group III (96.95) when compared to both the control group (128.73) and the group supplemented with 1/3 duckweed (104.02) (Fig. 1).

The concentration of total volatile fatty acids (TVFA) in the SRL (rumen liquid) depends on the amount of easily digestible carbohydrates, fermentable sugars, and the quantity and quality of CF. In this study, the concentration of TVFA ranged from 8.35 to 9.68 mM/dl SRL (Table 3). This variation can be attributed to the succession of events that occurred during carbohydrate fermentation in the rumen. The shift in substrate utilization during carbohydrate fermentation involves the initial utilization of easily fermentable sugars followed by structural carbohydrates (cellulose), which are fermented at a slower rate, with the maximum rate of

Table 2. *In vivo* Rumen fermentation parameters

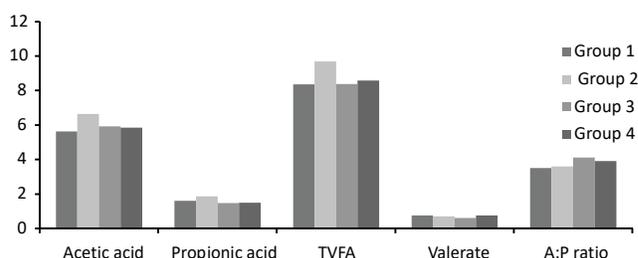| Parameters	Group 1	Group 2	Group 3	Group 4	SEM
Total nitrogen mg	250.07[c]	239.49[bc]	176.57[a]	189.70[ab]	11.01
NPN mg	128.73	104.02	96.95	89.81	6.97
TCA-N mg	121.34	135.38	79.62	99.89	10.79
NH3 mg	49.52	59.67	51.80	50.40	3.64
pH	5.82	5.76	6.14	6.11	0.059

Table 3. *In vivo* volatile fatty acids production (mM/dl) of different total mixed rations containing different levels of duckweed

Parameters	Group 1	Group 2	Group 3	Group 4	SEM
Acetic acid	5.62	6.64	5.91	5.84	0.17
Propionic acid	1.60	1.85	1.46	1.49	0.060
Iso butyric acid	0.037	0.048	0.036	0.051	0.003
Butyric acid	0.97	1.01	0.87	1.05	0.038
Iso valeric acid	0.055	0.068	0.051	0.061	0.005
Valeric acid	0.063[b]	0.067[b]	0.051[a]	0.064[b]	0.002
TVFA	8.35	9.68	8.38	8.57	0.24
Relative proportion (%)					
Acetate	67.24	68.60	70.62	68.02	0.54
Propionate	19.22	19.08	17.37	17.56	0.38
Iso butyrate	0.45	0.50	0.43	0.59	0.027
Butyrate	11.67	10.42	10.34	12.34	0.35
Isovalerate	0.66	0.69	0.61	0.71	0.041
Valerate	0.75[b]	0.69[ab]	0.61[a]	0.76[b]	0.021
A:P ratio`	3.50	3.59	4.11	3.91	0.11

Means bearing different superscripts in a row differ significantly (P<0.05)

breakdown occurring in the later stages of the digestion process. The results showed a non-significant difference among all four groups regarding TVFA concentrations. Specifically, the TVFA concentrations in the control and duckweed-supplemented groups varied from 8.35 -9.68 mM/dl for group and I and II (1/3 duckweed). However, a statistically significant difference was observed in valeric acid production, with the lowest value in the 2/3 duckweed supplemented group (III) and the highest value in the 1/3 duckweed supplemented group (II). The mean percentage of acetate was similar in all four groups (67.24- 70.62%, in groups I and III) .The percentage of propionate showed no significant variation among the groups. The butyrate percentage was also comparable across all four groups, ranging from 10.34% to 12.34, However, the percentage of valerate in rumen liquor was statistically higher in the 100% duckweed supplemented group (0.76) and the control group (0.75), and statistically lower in the 2/3 duckweed supplemented group (0.61). No significant effect on percent isovalerate was observed in both control and duckweed supplemented groups. The A: P ratio was lowest in the control group (3.50) and numerically higher in the 2/3 duckweed supplemented group (4.11) (Fig. 2).

The duckweed exhibits a VFA profile similar to that of soybean meal. The VFAs showed no significant differences between the control and duckweed supplemented diets. Comparing with study by Moore et al. (2002) on soybean meal and soybean hull diets, the present diet showed higher total VFA amounts than those reported for soybean meal and soybean hull. Additionally, the acetate to propionate ratio in diets was higher (3.50 mM for control to 4.11 for 2/3 duckweed) than in the soybean meal (3.06) or soybean hull (3.26) diets of Moore et al (2002). Damry et al (2001) and Huque et al (1996) concluded that incorporation of duckweed into a ruminant's diet had no detrimental effects. Damry et al (2001) reported that duckweed served as a good source of

undegradable protein for ruminants, contrasting with the earlier findings of Huque et al. (1996), which demonstrated high degradability of duckweed (87% for *Lemna*) when exposed to rumen conditions in bulls for 72 hours.

Blood biochemical aspects: Prior to the commencement of the experiment, blood samples were collected from the goats to evaluate their baseline values (Table 4, 5). All blood parameters were within the physiological range, indicating that the goats were in good health at the beginning of the study. Furthermore, no statistically significant effects on any
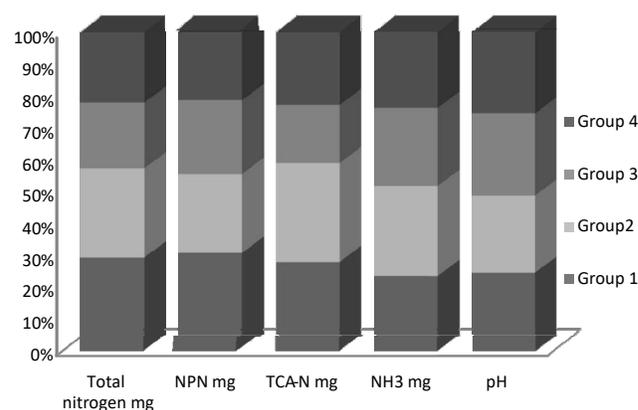
Fig. 1. *In vivo* Rumen fermentation parameters

Fig. 2. *In vivo* volatile fatty acids production (mM/dl) of different total mixed rations containing different levels of duckweed

Table 4. Blood constituents in male beetal goats at the start of experiment

Parameters	Group 1	Group 2	Group 3	Group 4	SEM
Triglycerides, mg/dl	12.40	13.17	16.88	12.71	2.37
GGT, (U/L)	47.63	45.00	46.66	54.95	3.17
Glucose, mg/dl	43.0	35.33	35.33	34.00	2.02
BUN, mg/dl	24.20	25.04	25.49	24.93	0.68
Creatinine, mg/dl	0.90	0.96	1.02	0.91	0.022
Cholesterol, mg/dl	56.42	75.36	71.27	57.0	3.74
ALT, (U/L)	16.38	17.40	20.19	20.11	0.93
AST, (U/L)	100.56	109.10	97.22	89.38	7.54
Total protein	6.58	6.47	6.74	6.58	0.15

Means bearing different superscripts in a row differ significantly (P<0.05)

Table 5. Blood parameters after feeding

Parameters	Group 1	Group 2	Group 3	Group 4	SEM
Triglycerides, mg/dl	15.68	15.27	16.28	15.86	2.03
GGT, (U/L)	42.61[ab]	43.26[ab]	38.44[a]	57.65[b]	2.86
Glucose, mg/dl	39.39	34.13	36.37	37.07	2.40
BUN, mg/dl	24.30	24.65	27.07	26.53	1.04
Creatinine, mg/dl	0.77[a]	0.85[ab]	0.93[b]	0.84[ab]	0.018
Cholesterol, mg/dl	40.50[a]	58.16[ab]	63.42[b]	49.54[ab]	3.69
ALT, (U/L)	20.22	19.60	20.37	20.39	0.57
AST, (U/L)	101.24	90.72	101.42	101.57	4.38
Total protein (g/dl)	6.29	6.37	6.73	6.74	0.13

Means bearing different superscripts in a row differ significantly (P<0.05)

of the blood parameters were observed throughout the course of the experiment. Effect of duckweed supplementation on blood glucose, triglycerides, GGT, creatinine, urea-nitrogen, cholesterol, ALT, AST and total indicate no significant effect of duckweed supplementation on triglycerides, GGT, Creatinine, ALT and AST in all groups. The serum triglycerides (mg/dl) were 15.68, 15.27, 16.28 and 15.86 respectively in all the four groups. The GGT (U/L) values were 42.61, 43.26, 38.44 and 68.11 whereas AST value (U/L) were 101.24, 90.72, 101.42 and 101.57 in groups I. II, III and IV respectively. The serum urea nitrogen concentration is closely associated with the breakdown of protein to amino acids and their deamination in rumen and the rate of utilization of NH_3 for bacterial protein synthesis. The increase in serum urea level may reflect an accelerated rate of protein catabolism rather than decrease in urinary excretion. The serum urea level also increases in renal tubular necrosis and decreases in hepatic insufficiency and low protein intake. Concentration of urea-N in blood serum are indicator of the adequacy or inadequacy of the nitrogen in the diet of animals and results revealed no statistically significant difference in 4 groups. The blood urea concentration (mg/dl) were 24.30, 24.65, 27.07 and 26.53 in all four groups respectively. Increased serum urea nitrogen is a sign of inefficient nitrogen utilization, but also indicates the diets were providing adequate N for the goat's requirements. With more N in the blood, more N is passed to the liver and consequently excreted as waste. Moore et al (2002) reports a serum urea nitrogen level of 15.39 mM for a hay and soybean meal diet and 13.75 mM for a soyhull diet. Their serum urea nitrogen was taken at 2.4 hours after feeding. Similar findings of our results were reported by Jhonson (1990) in sheep and observed no differences in plasma urea nitrogen (PUN) concentrations across treatments at the beginning of the trial. Plasma urea nitrogen concentrations were depressed for the steers on the 100% DW diet relative to the steers on the 100% SBM diet (0% DW) at day 14 (3.64 vs. 6.05 mg/dl) and again on day 21 (4.66 vs. 7.15 mg/dl; P < 0.03). Additionally, PUN concentrations were depressed for steers on the 25% DW diet compared to the steers on the 0% DW treatment (5.13 vs. 7.15 mg/dl). This would allow one to hypothesize that the ruminant animal more efficiently utilizes the protein found in duckweed. The serum creatinine concentration (mg/dl) varied from 0.77 to 1.03 in all four groups. The cholesterol is synthesized from fatty acids inside the body of animal. Its concentration in the serum is the reflection of the body fat metabolism. There no significant difference in serum cholesterol concentration in control and duckweed supplemented groups. The serum cholesterol concentration (mg/dl) was 40.50, 58.16, 63.42 and 49.54 in groups I, II, III and IV, respectively. The results were statistically non-significant. After the duckweed supplementation, blood glucose levels (mg/dl) were 39.39, 34.13, 36.37, and 27.07 for groups I, II, III, and IV, respectively. Similarly, the AST (aspartate aminotransferase -U/L) were 20.22, 19.60, 20.37, and 20.39 for the corresponding groups. However, statistical analysis revealed no significant differences in blood glucose levels or AST values among the groups. The total protein levels (did not differ significantly across all four groups.

CONCLUSION

The inclusion of duckweed in the diet of male goats led to a significant increase in blood cholesterol and creatinine levels compared to the control group, but these values remained within the physiological range. However, it is important to note that duckweed supplementation did not adversely affect rumen fermentation parameters, including pH, total nitrogen, non-protein nitrogen, ammonia nitrogen, total volatile fatty acids and trichloroacetic acid-precipitable nitrogen. Based on the results obtained, it can be concluded that the addition of duckweed meal to the diet did not have any adverse effects on the health status of the goats.

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New Distributional Record for *Siganus vermiculatus* (Valenciennes 1835) from the Veraval Fishing Landing Centre along Northwest Coast of India

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Abstract: A new distributional record of vermiculated spinefoot, *Siganus vermiculatus* (Valenciennes, 1835), belonging to the family Siganidae, for the first time from the northwest coast of India at Veraval fish landing centre ($20^0$54'03" N 70^0 22' 10" E) in Gir-Somnath district of the state of Gujarat on 23 March 2022. The morphometric and meristic characters of the specimen were measured using standard taxonomic keys. Further, DNA barcoding was carried out for the mitochondrial cytochrome oxidase subunit I gene from the tissues of the holotype specimen and phylogenetic studies using neighbor joining tree construction were done to ascertain the relationship and similarity with the specimens of the same species barcoded in the other places of southern India, and authentication of the specimens to *S. vermiculatus* was done. The species is reported from 900 km north of the previous nearest reported location.

Keywords: DNA sequencing, Gujarat, Siganus, Veraval, Vermiculatus, New distribution record, X-ray

The Siganidae family, also known as the rabbit fish family, is composed of a single accepted genus *Siganus,* with 29 species (Horton et al. 2022) possessing poisonous spines and having diurnal herbivore feeding behavior feeding mainly on benthic algae and microorganisms by scraping corals and rocks. Fifteen species have been reported from Indian waters of this family (Murugan and Namboothri 2012), out of which 2 species (*S. canaliculatus* and *S. javus*) were reported from Gujarat waters (Burman et al 2000). The common name rabbitfish is because of their rounded blunt snout, peaceful temperament and jaws having rabbit-like appearance. Siganid species can be identified by their color and morphological characteristics, such as snout shape, body depth, color patterns, shape of fins, etc., but some distinct key characters must be checked to prevent misidentification from closely related species (Woodland 1990). Siganids are marine-residing species that inhabit mainly reefs, sea grasses, mangroves, or shallow lagoons. They are important reef fishes that protect coral reefs from being smothered by algae. They are mostly marine, with a rare occurrence in estuaries, with the exception of *S. vermiculatus,* which is truly estuarine (Nelson 1994). *S. vermiculatus* can be cultured in ponds, tanks along with other fishes, crabs or as a mono cultured species. *S. vermiculatus* is one of the fastest growing species of genus *Siganus*. Efforts of captive breeding on a commercial basis are in progress (Anuraj et al. 2021). Siganids have venom glands in their dorsal, anal and pelvic fin spines that contain a painful toxin. The teeth are asymmetrical, bicuspid, and compressed into a single row. The dorsal fin comprise of 13 spines with 10 soft rays and the anal fin comprising 7 spines with 10 soft rays. They can attain a maximum length of 50 cm and have 23 vertebrates (Nelson 1994, Helfman et al 1997). The female siganids are larger than males in some but not all of the species (Kuiter 1993, Thresher 1984).

The present study has derived the meristic and morphological characteristics of the fish specimen collected from the western coast of India. Also, the gene sequence obtained was used to carry out BLAST with the NCBI GenBank database. Based on the maximum identity score, the first ten sequences were selected and aligned using multiple alignment software programs. The aim of the paper is, firstly, to report the presence of *S. vermiculatus* in Gujarat and the northward range extension of the species to about 900 km compared to its closest and previously recorded locations (i.e., Karwar coast).

MATERIAL AND METHODS

The study was carried out along the northwest coast of India, on the Veraval coast of the state of Gujarat (Fig. 1). The fish specimen was caught by FRP OBM using a bottom gill net from the inshore waters of Veraval (Fig. 2). The species-level identification was made by using standard taxonomic keys (Day 1888). The muscle and pectoral fin tissue samples were used for extracting DNA, and then its quality was evaluated on a 1.0% agarose gel. The fragment of the gene

was amplified by PCR with primers FISH_F2–FISH_R2. A single discrete PCR amplicon band was observed when resolved on a 1% agarose gel. The PCR amplicon was purified by column purification to remove contaminants. The DNA sequencing reaction of the PCR amplicon was carried out with both primers using the BDT v3.1 cycle sequencing kit on an ABI 3730xl genetic analyzer. The gene sequence was used to carry out BLAST with the NCBI GenBank database. COI gene, approximately 617bp length located in the mitochondrial genome was compared with the NCBI data based on nucleotide homology and phylogenetic analysis to know the specimen at species level.

RESULTS AND DISCUSSION

Systematics

Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Actinopteri
Subclass: Teleostei
Order: Acanthuriformes
Family: Siganidae
Genus: *Siganus*
Species: *vermiculatus*

Description: D. XIII 10, V. I 2-4 V, P. 14, A. VII 9, C. 16. Occurrence of 23 vertebrae (Fig. 3), bluish white body, head brownish or golden yellow with irregular blue lines making maze like pattern. Preopercular angle 91°-102°, strong overlapping scales cover cheeks, midline of thorax scaled, lacking pelvic ridges. Anterior nostril with low flange and slightly broadened posteriorly. Spines are stout, blunt or pungent and venomous. Head slightly concave above eye with head length 18.7% of standard length (SL) followed by head depth with 30.63% of SL. Snout length is 12.09% of SL. Eyes rounded with eye diameter 6.29% of SL, presence of forward directed spine in front of dorsal fin. First dorsal fin length is 6.34% of SL, second dorsal fin length with 10.56% of SL, third dorsal fin length with 12.5% of SL, fourth dorsal fin length with 12.79% of SL, fifth dorsal fin length with 13.05% of SL, sixth dorsal fin length with 12.17% of SL, seventh dorsal fin length with 12.5% of SL, eighth dorsal fin length with 12.5% of SL, ninth dorsal fin length with 12.84% of SL, tenth dorsal fin length with 11.20% of SL, eleventh dorsal fin length with 13.14% of SL, twelfth dorsal fin length with 11.85% of SL and thirteenth dorsal fin length with 11.21% of SL. Pelvic fin length is 16.05% of SL, pectoral fin length is 20.09% of SL, anal fin length is 15.94% of SL and caudal peduncle length is 4.9% of SL followed by caudal peduncle depth with 8.66% of SL. Caudal fin slightly emarginated; scales minute but distinct.

Table 1. Morphometric characters of *Siganus vermiculatus*

Character	Length (mm)
Total length	393.01
Standard length	308.27
Fork length	349.86
Head length	57.66
Snout length	37.28
Head depth	94.43
Snout to the end of preoperculum length	45.76
Orbit diameter	19.38
Upper-jaw length	17.95
Lower-jaw length	13.32
Caudal peduncle length	15.11
Caudal peduncle depth	26.70
Pectoral fin length	61.94
Pelvic fin length	49.47
Dorsal fin length	22.37
Anal fin length	49.15
Anal fin width	146.52
Dorsal fin base length	213.56
Anal fin base length	221.35
Pelvic fin base length	32.54
Opercular length	68.72
Predorsal length	75.56
Prepectoral length	70.12
Prepelvic length	88.24
Preanal length	161.92
Interorbital width	11.18
1st anal fin spine length	26.56
2nd anal fin spine length	38.54
3rd anal fin spine length	41.52
4th anal fin spine length	41.53
5th anal fin spine length	39.54
6th anal fin spine length	41.55
7th anal fin spine length	43.74
1st dorsal fin spine length	19.53
2nd dorsal fin spine length	32.54
3rd dorsal fin spine length	38.55
4th dorsal fin spine length	39.42
5th dorsal fin spine length	40.24
6th dorsal fin spine length	37.52
7th dorsal fin spine length	38.53
8th dorsal fin spine length	38.52
9th dorsal fin spine length	39.57
10th dorsal fin spine length	34.52
11th dorsal fin spine length	40.51
12th dorsal fin spine length	36.52
13th dorsal fin spine length	34.56

DNA Barcode: The mitochondrial cytochrome c oxidase (COI) gene, approximately 617bp length located in the mitochondrial genome (NCBI Sequence ID: OP476333) showed high similarity with *S. vermiculatus* based on nucleotide homology and phylogenetic analysis (Fig. 4) confirmed the fish sample at its species level.

Siganids belongs to the family Siganidae are found across the tropical and temperate Indo-West Pacific region and the Indian ocean. *S. vermiculatus* is commonly known for its light brownish body marked with irregular zigzag stripes. It was reported from the Veraval fishing landing centre from a gill netter, which is operated in nearshore water. The coral population in Gujarat is mostly found in the Gulf of Kachchh, but several reports support the existence of a patchy distribution of the coral in the intertidal and subtidal regions of Saurashtra (Raghunathan et al 2004). The fish is known to feed on algae growing on seagrasses, mangrove roots, and rocks. The coastal rocky shore of Gujarat, hence, can be a preferable feeding site for the species. This could be the result of the occurrence of species from Karwar to Veraval, as the southern Gujarat coast has a lacuna of rocky substratum. The fish is known to be one of the fastest-growing species, can feed on a variety of food items in captivity (El-Dakar et al 2010), and is also tolerant to a wide range of salinity, temperature, and pH, making them an ideal candidate species for mariculture.
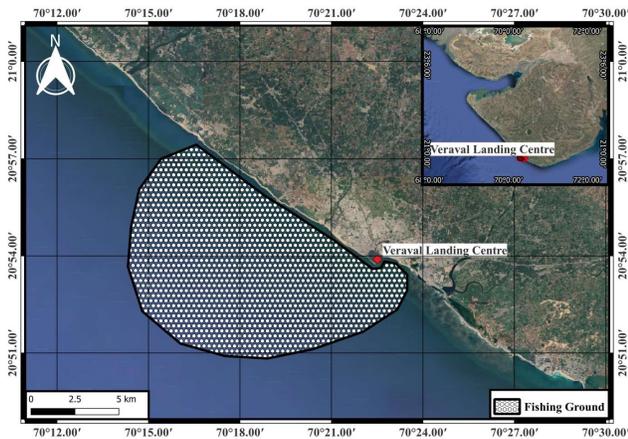
Fig. 1. Possible fishing ground of OBM gill netter
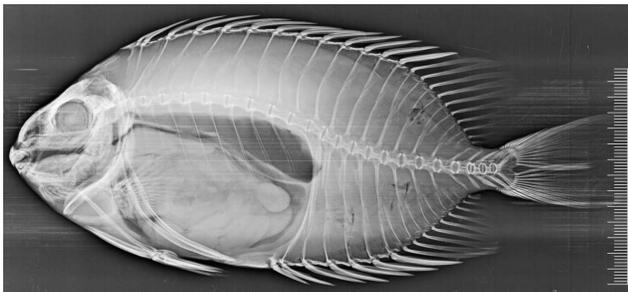
Fig. 3. X-ray of fish specimen

Fig. 2. Specimen of *Siganus vermiculatus* procured in this study
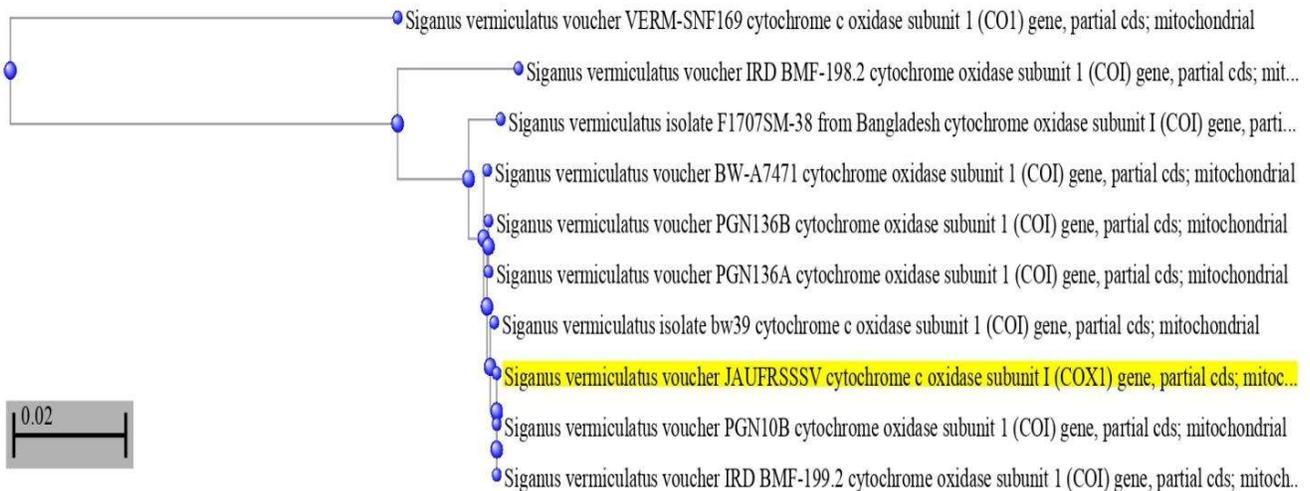
Fig. 4. Phylogenetic tree analysis

The taxonomic and DNA barcoding analyses have confirmed the collected specimen as *Siganus vermiculatus*. Globally, there are around 29 known species of Siganidae family (Froese and Pauly 2019), with 15 species described in India (Murugan and Namboothri 2012). On the west coast of India, three species of the Siganus genus are commonly available, among which *S. vermiculatus* has been reported to distribute upto Ratnagiri coast of Maharashtra (Metar et al., 2019). This study presents the first documentation of *S. vermiculatus* occurrence on the northwest coast of India, specifically at the Veraval fish landing centre. According to FAO identification sheets, *S. vermiculatus* can be distinguised from other Siganus species morphologically, by the presence of vermiculating lines on the sides, a characteristic observed in this study, which other signaus species do not possess. Additionally, *S. vermiculatus* is distinguished by having the longest last anal spine which aligns with the current study showing length of 43.74 mm in contrast, in *S. luridus* and *S. spinus* 3rd or 4th anal spine is the longest.

AUTHOR CONTRIBUTION

All the authors have significant contribution in the final manuscript. YM collected the fish sample and made the draft of the manuscript.

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Growth of *Pangasius hypophthalmus* in Sewage Treated Water

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Abstract: Treated sewage water constitutes a sustainable water resource that has been used for aquaculture. The suitability of sewage treated water for *Pangasius hypophthalmus* (Sauvage, 1878) was estimated during the present study in terms of growth parameters. *P. hypophthalmus* was cultured under three treatment groups: freshwater, sewage treated water without feed and with feed. The growth parameters of *P. hypophthalmus* in cultured in freshwater, sewage treated water with feed and without feed revealed higher weight (40.86 g), length (16.88 cm), weight gain (724.07 g), average daily weight gain (0.66 g/ day), biomass (817.20 g), percent increment in weight (1021.29%), percent increment in length (106.55%), specific growth rate (1.17%) and survival (100%) for fishes in sewage treated water with feed as compared to the other two treatments. Despite the absence of any external feeding, the fishes were able to survive in sewage treated water without feed as it is rich in nutrients, organic matter, micro-organism etc. The growth (weight, length) of *P. hypophthalmus* showed significant positive correlation with temperature (26.39^{0}C), conductivity (2.45 ms/cm), total dissolved solids (618.95 ppm), dissolved oxygen (6.10 mg/l), pH (7.86), hardness (283.30 mg/l) and salinity (1.36 ppt) of sewage treated water, however, ammonia (0.58 mg/l), nitrite (0.09 mg/l) and alkalinity (198.80 mg/l) had no correlation.

Keywords: Growth, *Pangasius hypophthalmus*, Treated sewage water, Water quality

During last six decades, Indian fisheries have grown more than seventeen folds with an increase in fish production from 0.752 million tons in 1950-51 to 14.16 million metric tons in 2019-20 (Anonymous 2020). In inland fisheries, Haryana stands second in the average annual fish production per unit area in the country. The average annual fish production in the state is 7000 Kg per hectare against a national average of 2900 Kg. There is a growing realization that freshwater will become a scarce resource in the foreseeable future with increasing population as well as with improvement in agricultural and industrial growth in India (Mukhopadhyay and Sarangi 2006). In addition, according to the Food and Agriculture Organization (FAO 2018) prediction for the early 2020s, aquaculture will only be able to cover 40 percent of global fish demand. In order to fill this fish demand-supply gap, aquaculture would need to grow globally in 9.9 percent every year. Hence, reuse of sewage effluent for aquaculture has been advocated due to scarcity of water resources. Treated wastewater constitutes a sustainable water resource that has been used for aquaculture in many countries including Germany (Prein et al 1990), Hungary (Etnier and Guterstam 1996), China (Phong Lan et al 2007), India (Roy et al 2011), and USA (Cuevas-Uribe and Mims 2014). Treated waste water use can reduce both the demand for freshwater and water costs in existing aquacultural operations, thus rendering the fish production more profitable. Few fishes like *Clarias batrachus*, *Heteropneustes fossalis*, *Channa* spp.,

Tilapia mossambicus and *Ctenopharyngodon idella* are cultured in sewage treated ponds as they can survive in water with lesser dissolved oxygen content (Samiksha 2019). Zaibel et al (2019) suggested that the yield of fish (*Poecilia reticulata*) grown in treated wastewater is potentially similar to that in freshwater, and the produced fish comply with the standards of consumer safety. Keeping these points in view, the effect of sewage treated water on *Pangasius hypophthalmus* growth parameters was evaluated in the present study.

MATERIAL AND METHODS

For present study, sewage treated water was collected from sewage treated ponds of the university and brought to the water quality laboratory of the College of Fisheries Science, CCSHAU, Hisar. The water was filtered to remove the twigs and debris before pouring into the glass aquariums. The aquariums were supplied with aerators to ensure the proper availability of oxygen. Before setting up the experiment, water quality parameters were estimated following standard methodology. The fishes were acclimatized for ten days at room temperature before the experimental setup. For *P. hypophthalamus*, three treatment groups *viz*, freshwater, sewage treated water without feed and sewage treated water with feed were designed under triplicate conditions to see the effect on weight, length and other growth parameters. Each replicate (aquarium of size 60

x 18 inches base, 24 inch height, 12 mm thick glass) contained 20 fishes and two aerators. The fishes of second treatment were fed commercial feed at the rate of 8 percent of their body weight twice a day. Observations on weight and length of *P. hypophthalmus* were measured at an interval of 10 days. Additionally, the temperature, pH, dissolved oxygen, alkalinity, total hardness, total dissolved solids, conductivity, salinity, ammonia nitrogen and nitrite nitrogen of the water were also estimated during each observation period. Sewage treated water was added regularly to maintain the water level. At the end of study period i.e. 90th day, growth parameters such as weight gain (g), percent increment in weight, percent increment in length, average daily weight gain (g/day), biomass (g), feeding rate (g/day), feed conversion ratio, specific growth rate (%) and survivability (%) was calculated by standard methodology(APHA, 2012). Weight (g) and length (cm) of the experimental fish was measured for the assessment of growth parameters by using electric weighing balance and scale, respectively.

Statistical analysis: For the statistical evaluation of the study, OPSTAT was used.

RESULTS AND DISCUSSION

Fish growth parameters in freshwater: There was significant increase in the weight and length of fish species from 0 to 90 day duration (Table 1). The fish weight was 3.68 g at 0 day which significantly increased to 28.71g at the end of study period. However, the fish weight during 0-10th day, 10th-20th day and 40th- 50thday was statistically comparable with each other. Fish length showed significant difference with each other during the whole experimental period with a 100% survivability. The weight gain, average daily weight gain and percent increment in weight ranged between 30.45 to 498.29 g, 0.12 to 0.48 g/day and 41.43 to 677.00 percent during 90 day study period. Likewise, percent increment in length was calculated as 13.72 percent at 10th day which increased to 91.16 cm at 90th day. There was a continuous increase in biomass (73.55 to 574.10 g) and feeding rate (58.70 to 287.05 g/ day). Feed conversion ratio (FCR) fluctuated between 1.70 and 3.56. At 50th- 60th day duration was minimum. Similarly, specific growth rate ranged between 0.99 and 2.00 percent in fresh water cultured *P. hypopthalamus*.

Fish growth parameters in sewage treated water without feed: Growth parameters of *P. hypophthalmus* in sewage treated water without feed assessed at different observation days in triplicate condition showed that there was an irregular trend in the weight and length of the fishes during 0 to 90 days duration (Table 2). Fish weight during 0th and 70th day did not show significant difference with each other. 50th day is

marked by significant decrease in the average weight of the fishes. At an interval between 50th-60th day, the weight was stagnant. A significant increase in weight was observed after 60th day till the end of experiment. There was significant increase in length of *P. hypophthalmus* from 8.42 cm at 0 day to 14.73 cm at 90th day. The increase in length was not significant. Other growth parameters also followed the similar trend. Thereafter, continuous increase in growth parameters was recorded due to addition of fresh sewage treated water. The irregular trend followed by *P. hypophthalmus* in sewage treated water without feed can be explained as sewage treated water is a rich source of planktons on which the fishes feed. As there was no artificial feeding, the fishes were completely dependent on the presence of planktons and the growth of planktons was directly related to the availability of organic matter, nutrients, micro-organisms etc. in the sewage treated water. The sudden decline at 50th day can be represented as decline in the number of planktons. On 60th day, 50 percent of fresh sewage treated water was added which resulted in the sudden increase in weight, length and other growth parameters of the fish at 60th-70th day duration. Weight gain, average daily weight gain, percent increment in weight, percent increment in length, biomass and specific growth rate ranged between 16.72 to 165.09 g, 0 to 0.27 g, 22.18 to 254.57 percent, 9.50 to 74.94 percent, 75.35 to 240.42 g and 0.43 to 0.93 percent respectively. The survivability of the fishes was 100 percent till 50th day and declined to 90 percent at 60thday due to the decline of planktons in sewage treated water without feed. Datta (2006) also reported that there is direct relationship between inflow of sewage and productivity of the ponds. Mandal et al (2021) observed ≥75% fish survival in sewage concentrations up to 50 percent after 30 days rearing of three fish species namely Labeo rohita*, Cirrhinus mrigala and *Labeo bata* whereas less than 50 percent fish survived in 75 percent sewage concentration.

Fish growth parameters in sewage treated water with feed: In treatment where feed was given to *P. hypophthalmus* in sewage treated water, results showed significant increase in all the growth parameters (Table 3). The fish survival was 100 percent under this treatment. With increase in observation days from 0 to 90 days, a significant increase in fish weight from 3.61 to 40.86 g was recorded. The fish weight at 10th (5.82 g) and 20th (6.91 g) day were statistically at par with each other. Fish length at different duration showed a significant increase till the end of study period (Table 2) from 8.17 to 16.88 cm at 90 days. Likewise, a continuous increase was recorded in weight gain, average daily weight gain, percent increment in weight, percent increment in length, biomass and specific growth rate. These

Table 1. Growth parameters of *Pangasius hypophthalmus* in fresh water at different durations

Observation days	Weight (g)	Length (cm)	Weight gain (g)	Average daily weight gain (g/day)	Percent increment in Weight	Percent increment in Length	Biomass (g)	Feeding rate (g/day)	Feed conversion ratio	Specific growth rate (%)
0	3.68[a]	8.38					73.55	58.70		
10	5.20[a,b]	9.53	30.45	0.16	41.43	13.72	104.02	83.20	1.92	2.00
20	6.38[b]	10.16	54.07	0.12	73.53	21.30	127.62	102.00	3.52	1.20
30	8.87	11.43	103.88	0.24	141.25	36.45	177.43	141.90	2.04	1.28
40	10.86[c]	12.07	143.66	0.19	195.35	44.03	217.22	108.60	3.56	1.16
50	12.42[c]	12.82	174.90	0.15	237.82	52.98	248.46	124.20	3.47	1.06
60	16.07	13.82	247.68	0.36	336.87	64.97	321.30	160.60	1.70	1.07
70	19.17	14.64	309.88	0.31	421.40	74.76	383.44	191.70	2.58	1.02
80	23.86	15.34	403.59	0.46	548.80	83.05	477.14	238.50	2.04	1.15
90	28.71	16.02	498.29	0.48	677.00	91.16	574.10	287.05	2.40	0.99

Values denoted by similar letter do not differ significantly with each other
The survivability for the experimental fish was 100% during the study

Table 2. Growth parameters of *Pangasius hypophthalmus* in sewage treated water without feed at different durations

Observation days	Weight (g)	Length (cm)	Weight gain (g)	Average daily weight gain (g)	Percent increment in weight	Percent increment in length	Biomass (g)	Specific growth rate (%)	Survivability (%)
0	3.77[a]	8.42[a]					75.35		100.00
10	4.60[a,b]	9.22[a,b]	16.72	0.08	22.18	9.50	92.07	0.87	100.00
20	5.77[b,c]	10.22[b,c]	39.65	0.12	53.22	21.30	115.45	0.93	100.00
30	6.25[d]	10.92[c]	49.65	0.04	65.99	29.69	125.07	0.73	100.00
40	7.78[d]	11.43[c,d]	80.14	0.15	106.34	35.74	155.50	0.78	100.00
50	6.80[c]	10.43[b,c]	60.71	0.00	80.59	23.87	136.07	0.51	100.00
60	6.80[c]	10.80e	60.71	0.00	80.59	28.26	136.07	0.43	90.00
70	8.06[d]	12.31[d]	69.68	0.12	113.88	46.15	145.03	0.47	90.00
80	11.09	13.87[e]	119.65	0.27	187.65	64.75	195.07	0.57	90.00
90	13.36	14.73[e]	165.09	0.25	254.57	74.94	240.42	0.61	90.00

Values denoted by similar letter do not differ significantly with each other

Table 3. Growth parameters of *Pangasius hypophthalmus* in sewage treated water with feed at different durations

Observation days	Weight (g)	Length (cm)	Weight gain (g)	Average daily weight gain (g)	Percent increment in weight	Percent increment in length	Biomass (g)	Feeding rate (g/day)	Feed conversion ratio	Specific growth rate (%)
0	3.61	8.17					72.88	58.20		
10	5.82[a]	9.68	44.32	0.21	59.77	18.45	116.45	93.10	1.31	2.04
20	6.91[a]	10.58	66.04	0.10	89.57	29.46	138.17	110.40	4.28	1.39
30	9.71	11.85	122.06	0.28	166.43	44.94	194.20	155.20	1.97	1.42
40	13.32	12.66	194.25	0.36	265.50	54.85	266.38	133.10	2.14	1.41
50	17.07	13.29	269.24	0.37	368.38	62.56	341.38	170.60	1.77	1.34
60	22.58	14.02	379.41	0.55	519.56	71.50	451.54	225.70	1.54	1.32
70	27.48	15.04	477.53	0.49	654.20	84.04	549.66	274.80	2.30	1.25
80	34.27	16.06	613.16	0.67	840.29	96.40	685.30	342.60	2.02	1.21
90	40.86	16.88	724.07	0.66	1021.29	106.55	817.20	408.60	2.50	1.17

Values denoted by similar letter do not differ significantly with each other
The survivability for the experimental fish was 100% during the study

ranged between 44.32 to 724.07 g, 0.10 to 0.67 g/day, 59.77 to 1021.29 percent, 18.45 to 106.55 percent, 72.88 to 817.20 g and 1.21 to 2.04 percent, respectively. The average daily weight gain was maximum at 80th day followed by 90th day. The maximum recorded feed conversion ratio was at 10th-20th day duration whereas the minimum feed conversion ratio was estimated at 40th-50th day duration.

Liney et al (2006) observed that *Rutilus rutilus* reared in ~80 percent secondary treated waste water for 300 days showed significantly larger post-hatch than fish reared in the tap water and the ~40% treated waste water. Dasgupta et al (2008) assessed water productivity in a controlled carp culture system (silver carp, *catla, rohu* and *mrigal*) in comparison to those involved in a fertilized based one and concluded that the sewage incorporation at 79.3×10^5 ha^{-1} yielded similar gross fish production as recorded from fertilizer based system, whereas net water productivity using sewage as nutrient source was found 64 percent higher than that of fertilizer based system. They observed better growth of fish in diluted sewage water than raw sewage water. The growth performance was significantly higher for fishes cultured in sewage treated water as represented in the present study on *P. hypophthalmus*.

Correlation between *Pangasius hypophthalmus* growth parameters and water quality: The sharp drop or an increase in the physico-chemical parameters of water causes stress to the fish which adversely affect its physiology. The weight of *P. hypophthalmus* showed significant positive correlation with temperature (0.96, 0.96), conductivity (0.91, 0.99) and salinity (0.92, 0.95) sewage

treated water without feed (Table 4) and sewage treated water with feed, respectively (Table 5). Temperature of the sewage treated water in the aquariums during present study ranged between 23° C to 33.5 °C. In different concentrations (25, 50, 75 and 100%) of sewage water, water temperature ranged from 27.53 to 30.47°C which was considered ideal for carp culture (Jana et al 2016). In the present study, the electrical conductivity of sewage treated water ranged from 2.02 mS/cm to 3.11mS/cm which is higher than reported for freshwater (0.61 to 0.78 mS/cm) (Reecha 2021). In the present investigation, the concentration of total dissolved solid (504 to 776 ppm) in sewage treated water was significantly higher than reported in the freshwater (155 to 248 ppm) (Reecha 2021). Khan et al (2017) recorded in ponds around Gurgaon canal, total dissolved solids was between 653 and740 mg/l. The salinity in the present study ranged from 0.3 to 1.74 ppt which is within permissible levels.
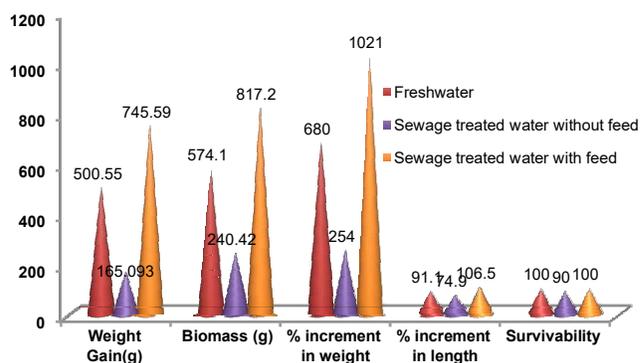
Fig. 1. Comparison of growth parameters of *Pangasius hypophthalmus* in fresh and sewage treated water

Table 4. Correlation between weight of *Pangasius hypophthalmus* (without feed) and sewage treated water quality parameters

Days	Fish weight (g)	Fish length (cm)	Temperature (°C)	Conductivity (ms/cm)	Total dissolved solids (ppm)	Salinity (ppt)	Dissolved oxygen (mg/l)	pH	Ammonia (mg/l)	Nitrite (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
0	3.77	8.42	23.10	2.02	565.00	0.99	6.00	7.70	0.00	0.00	260.00	180.00
10	4.60	9.22	24.80	2.03	504.00	1.14	3.50	7.80	2.30	0.01	200.00	220.00
20	5.77	10.22	24.80	2.11	528.00	1.19	3.50	7.80	1.50	0.25	174.00	200.00
30	6.25	10.92	24.20	2.19	547.50	1.23	6.50	7.60	0.70	0.21	260.00	180.00
40	7.77	11.43	26.20	2.29	572.50	1.29	7.00	7.40	0.20	0.30	313.00	200.00
50	6.80	10.43	26.60	2.37	592.50	1.33	7.50	7.60	0.20	0.03	310.00	220.00
60	6.80	10.80	26.50	2.62	655.00	1.47	6.50	7.80	0.20	0.01	303.00	220.00
70	8.06	12.31	26.90	2.85	711.50	1.59	6.50	8.30	0.20	0.00	300.00	240.00
80	10.84	13.87	30.10	2.95	737.00	1.65	6.50	8.40	0.20	0.07	303.00	148.00
90	13.36	14.73	30.70	3.11	776.50	1.74	7.50	8.20	0.30	0.03	410.00	180.00
Mean	7.40	11.24	26.39	2.45	618.95	1.36	6.10	7.86	0.58	0.09	283.30	198.80
Correlation with weight			0.96	0.91	0.87	0.92	0.55	0.63	-0.38*	-0.06*	0.79	-0.36*
Correlation with length			0.93	0.92	0.87	0.94	0.52	0.68	-0.37*	-0.01*	0.73	-0.35*

*Non-significant at 5%

Table 5. Correlation between weight of *Pangasius hypophthalmus* (with feed) and sewage treated water quality parameters

Days	Fish weight (g)	Fish length (cm)	Temperature (^{0}C)	Conductivity (ms/cm)	Total dissolved solids (ppm)	Salinity (ppt)	Dissolved oxygen (mg/l)	pH	Ammonia (mg/l)	Nitrite (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
0	3.64	8.17	23.00	2.02	565.00	0.99	4.50	7.60	0.00	0.00	260.00	180.00
10	5.82	9.68	24.10	2.03	506.00	1.14	3.00	8.20	2.50	0.05	240.00	200.00
20	6.91	10.58	24.70	2.08	523.00	1.18	3.00	7.80	1.60	0.28	176.00	180.00
30	9.71	11.85	24.90	2.19	548.00	1.23	6.50	7.20	0.80	0.30	280.00	160.00
40	13.32	12.66	26.30	2.21	553.50	1.25	7.50	7.40	0.20	0.40	306.00	240.00
50	17.07	13.29	26.70	2.31	576.50	1.30	6.50	7.80	0.30	0.03	306.00	220.00
60	22.58	14.02	26.80	2.36	589.50	1.33	6.50	7.30	0.30	0.03	292.00	160.00
70	27.48	15.04	27.00	2.48	620.00	1.39	7.50	8.20	0.20	0.01	379.00	280.00
80	34.26	16.06	30.40	2.55	636.50	1.44	6.00	8.10	0.30	0.10	385.00	174.00
90	40.86	16.88	30.70	2.70	675.00	1.51	7.00	8.20	0.20	0.28	407.00	190.00
Mean	7.40	11.24	26.39	2.45	618.95	1.36	6.10	7.86	0.58	0.09	283.30	198.80
Correlation with weight			0.96	0.99	0.94	0.95	0.61	0.45*	-0.48*	-0.01*	0.90	0.13*
Correlation with length			0.95	0.97	0.86	0.99	0.71	0.32*	-0.47*	0.10*	0.86	0.19*

*Non-significant at 5%

Non-significant correlation was recorded with Ammonia and nitrite in sewage treated water without feed and with feed. The total dissolved solids (0.87, 0.94), dissolved oxygen (0.55, 0.61) and hardness (0.79, 0.90) of sewage treated water without feed and with feed were positively correlated with *P. hypophthalmus* weight, however, alkalinity of sewage treated water did not show any correlation with weight of *P. hypophthalmus*. The temperature (0.93, 0.95), conductivity (0.92, 0.97) and salinity (0.94, 0.99) of sewage treated water without feed and sewage treated water with feed, respectively showed positive correlation with the length of *P. hypophthalmus*. However, a non-significant correlation was observed between length and water quality of sewage treated water without feed and sewage treated water with feed in terms of its ammonia, nitrite and alkalinity. Data analyzed for the total dissolved solids (0.87, 0.86), dissolved oxygen (0.52, 0.71) and hardness (0.73, 0.86) of sewage treated water without feed and with feed were significant and positively correlated with the length of *P. hypophthalmus*. However, pH of sewage treated water with feed did not affect the length of *P. hypophthalmus*. In contrast, pH of sewage treated water without feed affected the length of *P. hypophthalmus* during the study period.

In the present study, pH ranged from 7.0 to 8.4 which are ideal for fish culture as earlier reported by Santhosh and Singh (2007). The suitable pH range for fish culture is 6.7 to 9.5 and the ideal level is 7.5 to 8.5. Bhatnagar and Devi (2013) observed that ammonia is the by-product of protein metabolism excreted by fish and bacterial decomposition of organic matter such as wasted food, dead plankton, sewage

etc. The ammonia concentration in sewage treated water is between 0.00 to 2.5 mg/l during the observation period which is corroborated with earlier studies by Bansal et al. (1997) where the ammonia concentration from 0.2 to 3mg/l was observed in waste fed aquaculture system. In the present study, the levels of hardness in the sewage treated waters remained near to the optimum level throughout the observation period. The alkalinity observed during the study period was 76 to 280 mg/l which was in agreement with studies conducted by Sharma et al. (2019) in sewage treatment plant ranging from 63 to 626 mg/l.

CONCLUSION

The cursory analysis of growth parameters of *P. hypophthalmus* reared in three different treatments (freshwater, sewage treated water without feed and sewage treated water with feed) revealed that the fish is suitable to culture in sewage treated water. Even without any external feeding, the fish was able to thrive in the environment. A higher growth in sewage treated water with feed compared to the freshwater explains the fact that presence of nutrients in the sewage water enhances the planktonic populations which adds up in the effective feeding of the fishes. The culturing the fishes in sewage treated water would help to increase the yield of the fish as well as reduce the dependency of freshwater in fisheries sector production which is an important factor that directly affects the fish's growth rate, health, survival and economics of the system.

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Effect of UV Radiations on Vitamin D$_2$ Content and Nutritional Composition of Button (*Agaricus bisporus*) and Oyster (*Pleurotus florida*) Mushrooms

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Abstract: Button (*Agaricus bisporus*) and oyster (*Pleurotus florida*) mushrooms irradiated with ultraviolet (UV) radiations (UV-A, UV-B and UV-C) at a distance of 30, 45 and 60cm and with sun rays for 10, 20 and 30min followed by freeze drying resulted in an enormous increase in vitamin D$_2$ content. The irradiation dose of treating mushrooms for 30 min with UV-A, UV-B and UV-C was 17.9, 21.5 and 15.7 kJ/m^2, respectively. Irradiation of mushrooms with UV-B rays at a distance of 60 cm for 30 min resulted in the maximum spike in vitamin D$_2$ content with 228 and 141 folds increase in button mushrooms and oyster mushrooms, respectively. Freeze dried UV-B treated mushroom powder were significantly high in *in-vitro* protein digestibility and total phenols. The supplementation of UV treated button and oyster mushroom powder in traditional food recipe led to a significant increase in vitamin D$_2$ content, protein, ash, fibre and minerals like iron, copper, phosphorus, potassium, zinc and selenium, total phenol and *in- vitro* protein digestibility as compared to the control (without mushroom powder). There was retention in vitamin D$_2$ in the mushroom powder after incorporation in the food product. This vitamin-D$_2$ enriched mushroom powder can be extensively used as a food based approach to combat the problem of vitamin-D deficiency and to boost immunity. Mushroom powder and its supplemented food product stored in air tight glass containers for 5 months had negligible microbial growth.

Keywords: Button and Oyster mushrooms, Vitamin D$_2$ UV radiation, *in-vitro* protein digestibility, Total phenols

Vitamin D, the sunshine vitamin, has an important role in calcium and phosphorus metabolism. The prevalence of vitamin D deficiency ranges from 40% to 99%, with most of the studies reporting a prevalence of 80-90% and the prevalence is high all the age groups (Gupta and Gupta 2014). The main reason for this deficiency could be lack of sunlight exposure due to increased indoor lifestyle, increased pollution and reduced intake of vitamin D containing food. Vitamin D is present in two forms D$_2$ and D$_3$. Vitamin D$_3$ is mainly found in animal foods like eggs and fish whereas D$_2$ can be found in plant based sources (Barnkob et al 2016). Vitamin D may also be obtained from animal based food sources and dietary supplements (Elangovan et al 2017).Vitamin D is mostly present in the animal foods but the majority of the population in India is vegetarian so they are just left with a few options. Mushrooms being the only vegetarian food which contains Vitamin-D and this quantity can be enhanced by exposing the mushrooms to UV radiations and sunlight. Mushrooms are exactly similar to the skin of a human, can produce vitamin D on exposure to UV rays. A series of photochemical reactions occurring during the exposure process that leads to the conversion of

ergosterol present on the mushroom surface to ergocalciferol (Vitamin D$_2$). This amount is quite high as compared to the amount of vitamin D present in the fortified foods. As fortified milk (100 g) has approximately 37 IU of vitamin D, whereas there could be an average amount of 19,000 IU of vitamin D in mushrooms (100g) irradiated with a dose of 15 KJ/ m^2 of UV-B (Aborhyem et al 2020). There is high prevalence of vitamin D deficiency all over the world and the synthetic supplements of vitamin D may not be easily available during this pandemic situation, so it is important to find out some locally available foods that are cost effective, natural, rich source of vitamin D and other macro and micro-nutrients, further would help to promote community health (Panarese and Shahini 2020).

Mushrooms are considered as a super food with huge benefits. Treatment of mushrooms with UV rays enhances their nutritional parameters (vitamin D$_2$ content, total phenols, *in-vitro* protein digestibility and fatty acid composition) for which Indian mushroom varieties need to be explored. Consumption of mushrooms exhibit great health benefits such as anti-inflammatory, antioxidant, antimicrobial, antitumor, hypoglycemic and antihypertensive (Carocho and Ferreira 2013a, Carocho and Ferreira 2013a, Alves et al

2013, Taofiq et al 2016). Since there is a glut production of mushrooms in winter season and it is a highly perishable crop due to high moisture content, so there is a need for value addition at commercial level. Processing of mushrooms into powder form will not only make them available throughout the year for better revenue generation but also provide a nutrient dense food for better nutritional security. The objective of this research was to explore the most suitable protocol to maximize the vitamin D_2 content in button and oyster mushrooms(both the varieties are widely consumed in an Indian scenario) using different UV rays in terms of wavelengths, intensity, distance, time duration of exposing these mushrooms to the UV rays. Then the UV treated mushrooms were further processed into powder to enhance their shelf life and incorporated in the Indian traditional recipe (*panjiri*) that would act as a food vehicle for improving the nutritional status of vitamin D deficient population.

MATERIAL AND METHODS

Raw material for experimentation: The samples of untreated fresh post-harvest button mushrooms (*Agaricus bisporus*) and oyster mushrooms (*Pleurotus florida*) were procured from the Department of Microbiology, College of Basic Sciences, PAU, Ludhiana. Mushrooms of medium size used for experiment were harvested in morning time and transferred for processing in sealed containers in order to prevent the exposure to light before the irradiation to UV light. The moisture content of both the varieties of mushrooms were adjusted to around 80% by vacuum drying at 25° C before the start of the experiment for the maximum vitamin D_2 formation. For each treatment 100$\pm$15 gm of the mushroom sample was taken. Fresh button mushroom and oyster mushroom were treated in triplicate with different ultraviolet (UV) rays(UV-A, UV-B and UV-C) using different distances (30, 45 and 60 cm) from the source of irradiation and for different time durations (10, 20 and 30 min) in an irradiation chamber thus making a total of 162 samples.

Effect of duration and distance of UV rays on ergosterol conversion to Vitamin D_2: Fresh Button mushroom (*Agaricus bisporus*) and Oyster mushroom (*Pleurotus florida*) with different ultraviolet (UV) rays (UV-A, UV-B and UV-C) were treated in an irradiation chamber (made under the guidance of National Research Centre for Mushroom (NRCM), Solan). The dimensions of the chamber were 100 × 75 × 60 cm. Since UV rays does not pass through the PVC, all six surfaces of the chamber were covered by PVC sheets. The UV bulb were attached to a holder on the top center of the chamber, which has three removable internal stainless steel trays. The chamber allowed adjusting the distance between the tray and UV light source at 30, 45 and 60 cm.

Medium sized mushrooms were sliced longitudinally and placed in the chamber with their gills upwards towards the radiation source for UV treatment for different time duration and at different distance. The gills side of the mushrooms were irradiated for 10, 20 and 30 min with ultra violet lights: UV-A bulb (wave length 315-400 nm , Philips TLD-100 watt with the intensity at 30 cm of 9.8 W/m^2), UV-B bulb (wave length 280-315 nm, Philips TL-100 watt/01 with intensity at 30cm of 11.5 W/m^2) and UV-C bulb (wave length 100-280nm, G18T8 units with intensity at 30 cm of 8.3 W/m^2) . Irradiated mushrooms were stored at -20ºC for 24 hrs. Mushrooms treated with UV-A, UV-B and UV-C had 0.59, 0.70, and 0.50 kJ/m^2/min of the irradiation doses rate and the doses of calculated radiation after 30 min of irradiation were 17.9, 21.5 and 15.7 kJ/m^2, respectively. The UV source showed a stable intensity and spectral distribution over the entire period of 30 min. During all steps of preparation, the mushroom samples were not exposed to incidental ultraviolet light. Mushroom samples were freeze dried at -40°C for 36-48hrs and pulverization into fine powder and stored in tight sealed aluminum coated poly bags. Non-irradiated mushrooms were freeze dried as a control. Nutritional evaluation of treated button and oyster mushroom powder was done which included fatty acid composition, total phenols, *in vitro* protein digestibility and vitamin-D_2 content. The traditional Indian food product supplemented with treated mushroom powder was analyzed for proximate composition, mineral content, total phenols, *in vitro* protein digestibility and vitamin D content.

Nutritional and Biochemical Analysis of UV Treated Mushroom Powder and its Supplemented Product

Vitamin D_2 estimation: AOAC 2002.05 after the addition of an internal standard (vitamin D_2) and basic hydrolysis, vitamin D_3 was extracted with *n*- heptane. The fraction that contains vitamin D_2/D_3 was separated by preparative normal-phase liquid chromatography (LC). After evaporation and dilution in acetonitrile-methanol, vitamin D_2 was determined by reversed-phase LC with UV detection at 265nm. A separate test portion was analyzed in parallel to confirm the absence of endogenous vitamin D_2 (AOAC 2012). Vitamin D_2 was qualified using formula given below:

$$\text{Quantity of vitamin } D_2 \ (\mu g/g) = \frac{\substack{\text{Std concentration} \times \text{Area of sample} \\ \times \text{ Final volume} \times \text{Dilution factor}}}{\text{Area of standard} \times \text{Weight of sample}}$$

Proximate composition: The highly acceptable experimental products along with their control samples were dried in hot air oven and milled with a grinder (Philips Grinder HL 1631/00) until a homogenous fine powder was obtained and were analyzed for proximate composition (moisture,

protein, fat, ash, carbohydrates and energy) using standard AOAC method (AOAC 2010)

Mineral estimation: The minerals namely iron, copper, phosphorus, potassium, zinc and selenium were analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP- OES) method using ICP optical emission spectrophotometer (ICP-OES Optima 2100 DV) after wet digestion (AOAC 2012).

Total phenolic content: For estimation of TPC methanol extract of samples were used. Estimation of TPC was conducted by Folin-Ciocalteu method (Mathur and Vijayvergia 2017). The total phenols in the sample were expressed as mg GAE (Gallic Acid Equivalent)/100g of dry weight.

Fatty acid composition (**Appleqvist 1968):** Fatty acid composition of food samples was estimated using gas liquid chromatography (GLC). The EZ chrome elite software was used to compute the fatty acid composition.

***In-vitro* protein digestibility:** Dry sample (0.5g) was taken in 250ml conical flask and added 50ml of pepsin solution Incubation at 37°C for 24 hrs was done. The residue was analyzed for N_2 content by macro- kjeldahl method. The digestibility coefficient was determined by subtracting the residue protein from the initial protein on the basis of 100g of sample (Singh et al 1989).

Shelf life evaluation: UV treated mushroom powders were stored and the developed indigenous products for a period of 5 months in a different packaging materials such as ziplock polythelene bags, glass container and plastic container at room temperature and further evaluated for shelf life (Thatcher and Clark 1968) for the presence of bacterial and yeast/ mold growth.

Statistical estimation: Multivariate analysis was used to study the effect of distance and time of exposure to different UV radiations on vitamin D_2 content. Independent sample t-test was applied for the comparison of nutritional parameters-proximate composition, mineral content, fatty acid composition, total phenols and *in vitro* protein digestibility between control sample and experimental sample by using computer software JMP 10.0.1.

RESULTS AND DISCUSSION

Formation of Vitamin D_2 in button and oyster mushroom: There was a significant effect of UV rays, distance and time interaction, on vitamin D_2 content of button mushroom when treated with different UV rays (Table 1). The vitamin-D_2 content of button mushroom treated with UV-A, UV-B, UV-C and sun rays was significantly higher at 7, 228, 43 and 59 folds in comparison to the control (Untreated button mushroom) when exposed at maximum distance of 60cm for

maximum time duration at 30 min. The significant increase in vitamin D_2 content of *A. biporus* irradiated with UV-B rays is reported by earlier scientists (Simon et al 2011, Urbain and Jakobsen 2015, Bilbao- Sainz et al 2017). Exposure of fresh mushrooms to different wavelengths of UV radiations after harvesting lead to a tremendous increase in vitamin D_2 content reaching upto 40 g/g dried mass (ca 320 g/100 g FW) (Urbain and Jakobsen 2015, Koyyalamudi et al 2009, Urbain et al 2016). Ko et al (2008) reported UV-B radiation as the most effective wavelength to stimulate the production of vitamin D_2 in mushrooms (280-315 nm). Contrary to the results reported in the present research some researchers have reported UV-A 315-400 nm (Koyyalamudi et al 2009) and UV-C (<280 nm) radiations (Urbain et al 2016, Ko et al 2008) as a potential wavelength to enhance the vitamin D_2 content in mushrooms. There was a significant effect of UV rays, distance and time interaction, on vitamin D_2 content of oyster mushroom when treated with different UV rays (Table 2). For oyster mushroom exposed to all three UV rays such as UV-A, UV-B and UV-C rays, Vitamin-D_2 content was significantly increased by 1.19, 141 and 14 folds at the maximum distance of 60 cm for maximum time duration at 30min as compared to control (untreated oyster mushroom).Oyster mushroom when exposed to sun rays for 30 min, 10 folds increase in vitamin-D_2 was observed as compared to control oyster mushrooms. Thus UV-B rays significantly increased vitamin-D_2 content of oyster mushroom as compared to other treatments. Various researchers have emphasized the use of different UV

Table 1. Comparison of vitamin D_2 (µg/100g) content of button mushroom treated with various UV rays

Distance (cm)	Time (min)		
	10	20	30
Button mushroom treated with UV-A Rays			
30	21.60 ± 0.44	24.10 ± 0.57	31.87 ± 0.19
45	23.55 ± 0.18	25.52 ± 0.32	33.87 ± 0.45
60	26.70 ± 0.41	29.01 ± 0.54	36.57 ± 1.04
Button mushroom treated with UV-B Rays			
30	505.88 ± 5.12	730.6 ± 7.11	774.66 ± 6.29
45	796.45 ± 6.39	844.56 ± 2.71	886.73 ± 6.54
60	915.82 ± 3.71	1146.49 ± 4.01	1250.13 ± 1.05
Button mushroom treated with UV-C Rays			
30	111.21±0.62	131.38 ±1.08	157.69 ±2.20
45	148.09 ±2.30	182.13 ±1.45	202.68 ±2.09
60	223.15 ±2.63	232.30 ±2.82	237.88 ±2.65

Values are given in mean ± SD
Vitamin D_2 content of control (un-irradiated button mushrooms) was 5.48 ± 0.34 µg/100g

radiations in increasing the vitamin D_2 content of oyster mushrooms. *Pleurotus ostreatus,* the most common species of *Pleurotus* genus (oyster mushroom) reported the conversion of ergosterol to active form of vitamin D_2 on irradiation with UV-A rays (Ko et al 2008). The enhancement in vitamin D_2 on exposure to UV-B rays was reported (Banlangsawan and Sanoamuang 2016) and with UV-C rays (Slawinska et al 2016). Thus UV-B rays significantly increased vitamin-D_2 content of both Button and Oyster Mushroom as compared to other treatments and this UV-B treated button and oyster mushroom powders were further supplemented in various traditional Indian food recipe like

Table 2. Comparison of vitamin D_2 (µg/100g) content of oyster mushroom treated with various UV rays

Distance (cm)	Time (min)		
	10	20	30
Oyster mushroom treated with UV-A Rays			
30	88.38 ±1.08	91.30 ±0.65	94.67 ±1.37
45	90.09 ± 0.54	93.85 ± 2.84	97.05±1.58
60	93.36 ±2.19	95.34 ±0.61	99.54 ±0.58
Oyster mushroom treated with UV-B Rays			
30	4522.23 ±0.97	7753.68±3.96	9375.69 ±3.01
45	5453.67±2.33	8103.01±2.76	10305.14±3.84
60	6721.90±1.22	8956.09±2.45	11687.3±2.05
Oyster mushroom treated with UV-C Rays			
30	1133.87 ±1.11	1147.97 ±1.88	1176.63 ±2.97
45	1148.19 ± 2.58	1155.53 ± 3.55	1182.45 ±2.94
60	1168.66 ±2.52	1175.11 ± 3.51	1192.30 ± 1.50

Vitamin D content of control (un-radiated oyster mushrooms) was 83.17 ± 2.02 µg/100g

panjiri at different 10 and 15% levels, respectively.

Nutritional Evaluation UV-B treated Button and Oyster Mushroom Powder Supplemented Products

Proximate composition: The incorporation of UV-B treated button and oyster mushroom in the traditional Indian recipe like *panjiri* significantly improved the nutritional composition in terms of protein, fat, ash and fibre content as compare to control p*anjiri* prepared by using only whole wheat flour (Table 3). The vitamin D_2 enriched mushroom powder when incorporated in *panjiri* was further analyzed for its Vitamin D content. The vitamin D_2 content of the mushroom powder after incorporation in the food product retained as such with no deterioration. This enriched quality of vitamin D_2 is retained in mushroom powder supplemented food products. The vitamin D_2 content of *panjiri* supplemented with Vitamin D_2 enriched button mushroom powder at 10% of supplementation was 125ug/100 mg and with oyster mushroom powder at 15% was 1753µg/100mg. In case of control *panjiri* with no mushroom powder had zero vitamin D_2 content. Thus the proximate composition and vitamin D_2 content of UV-B treated button and oyster mushroom supplemented *panjiri* was enhanced which can further help to improve the nutritional status of the population by incorporating these mushroom powders in the traditional food recipes. The results of the present study are in accordance with the results of the previous researches which reported an enhancement of nutritional composition of traditional products by the addition of mushroom powder (Ishara et al 2018). The addition of button and oyster mushroom powder significantly enhanced the overall nutritional composition of *panjiri* in terms of protein, ash, fibre and fat content.

Table 3. Proximate composition UV-B treated button and oyster mushroom powder supplemented products (on dry weight basis)

Panjiri	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrate (%)	Energy (Kcal)
Panjiri supplemented with treated button mushroom powder						
Control	4.12±0.29	26.55±1.21	0.95±0.12	0.79±0.13	64.67±2.01	514.10±3.54
Experimental (10% TBMP)	6.69±0.72	27.29±1.07	1.83±0.10	2.86±0.22	58.47±0.77	510.22±1.77
│t│-Value	5.727	0.789	10.041	13.976	4.995	1.701
p-Value	0.005	0.474	0.001	<0.0001	0.008	0.164
Panjiri supplemented with treated oyster mushroom powder						
Control	4.12±0.29	26.55±1.21	0.95±0.12	0.79±0.13	64.67±2.01	514.10±3.54
Experimental (15% TOMP)	5.08±0.23	26.95±1.16	1.30±0.10	3.09±0.18	61.05±1.06	507.56±6.55
│t│-Value	4.521	0.418	3.880	17.799	2.762	1.522
p-Value	0.011	0.697	0.018	<0.0001	0.051	0.203

CBMP- Control Button Mushroom Powder (un-radiated)
TBMP- UV-B Treated Button Mushroom Powder at the distance of 60 cm for 30 min
COMP- Control Oyster Mushroom Powder
TOMP- UV-B Treated Oyster Mushroom Powder at the distance of 60 cm for 30 min
 t-values are absolute values

Mineral content (dry weight basis): There was a significant increase in the mineral content (iron, copper, phosphorus, potassium, zinc and selenium) of *panjiri* supplemented with 10% of UV-B treated Button and 15% UV B treated oyster mushroom powder as compared to control *panjiri* (Table 4). These results are in accordance with the results reported in previous years where *panjiri* supplemented with other functional foods led to a better nutritional composition in terms of its mineral composition (Kaur and Sharma 2017, Dhanesh et al 2018).

Nutritional Composition of UV-B Treated Mutton and Oyster Mushrooms

Fatty Acid composition: There was a significant decrease in linoleic acid in UV treated button and oyster mushrooms as compared to control mushrooms (Table 5). In oyster mushrooms, there was a significant increase in oleic acid after UV treatment. Saturated fatty acid also significantly increased in oyster mushrooms after UV treatment, though it decreased non-significantly in button mushroom. The variation in the fatty acid composition of treated button and oyster mushroom powder might depend on the cellular mechanism of lipid metabolism. Acetyl-CoA carboxylase is an enzyme that plays a key role in fatty acid synthesis which is dependent upon the availability of ATP's (adenosine triphosphate). Biosynthesis of PUFA requires large amount of ATP's than SFA's and MUFA's production. UV exposure may decrease the availability of ATP's for the synthesis of fatty acids which can cause decrease in linoleic fatty acid composition of UV treated button and oyster Mushroom Powder. Guihéneuf et al (2010) also observed that UV treatment led to reduction in PUFAs such as 20% in EPA and 16% in DHA in two marine microalgae *Pavlova lutheri* (*Pavlovophyceae*) and *Odontella aurita* (*Bacillariophyceae).*

Total phenols: There was a significant increase in total phenols in mushrooms after UV B radiations (Table 6). UV-B exposure causes the abiotic stress in plants that produces two natural enzymes, polyphony alanine ammonia-lyase and chalcone synthase as a mechanism to adapt the stress

Table 4. Mineral content of UV-B treated button and oyster mushroom powder supplemented products (on dry weight basis)

Panjiri	Iron (mg/100g)	Copper (mg/100g)	Phosphorus (mg/100g)	Potassium (mg/100g)	Zinc (mg/100g)	Selenium (mg/100g)
Mineral content of panjiri supplemented with UV-B treated button mushroom powder						
Control	1.53±0.06	1.82±0.12	396.01±1.09	339.53±1.26	0.10±0.02	0.04±0.01
Experimental (10% TBMP)	4.21±0.11	3.76±0.15	636.76±0.63	673.47±0.67	1.62±0.11	0.89±0.03
｜t｜-Value	20.590	10.132	191.370	234.546	14.021	26.849
p-Value	<0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001
Mineral content of Panjiri supplemented with UV-B treated oyster mushroom powder						
Control	1.53±0.06	1.82±0.12	396.01±1.09	339.53±1.26	0.10±0.02	0.04±0.01
Experimental (15% TOMP)	5.29±0.16	4.03±0.02	703.95±2.20	710.08±0.92	2.55±0.21	0.23±0.02
｜t｜-Value	21.370	18.271	125.586	238.432	11.590	9.848
P-Value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.001

Values are mean± SE, See Table 3 for details

Table 5. Fatty acid composition of UV treated button and oyster mushroom powder (on dry weight basis)

Treatment	Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2,ω-6)
Fatty acid composition of button mushroom powder				
CBMP	14.55 ±0.11	5.68 ±0.06	4.66 ±0.19	76.00 ±0.14
TBMP	14.73 ±0.03	5.80 ±0.06	3.90 ±0.35	74.78 ±0.10
｜t｜-Value	2.602	2.376	3.372	12.414
p-Value	0.060	0.076	0.028	<0.0001
Fatty acid composition of oyster mushroom powder				
COMP	16.60±0.09	4.92±0.33	25.71±0.01	52.85±0.27
TOMP	17.09±0.27	6.75±0.03	28.96±0.04	47.16±0.25
｜t｜-Value	3.083	9.554	137.60	26.934
p-Value	0.037	0.001	<0.0001	<0.0001

See Table 3 for details

conditions which further synthesize the phenolics and chemical compounds. Thus this led to the growth of phenolic compounds in the plants (Liu et al 2011). Similar results, regarding increase in total phenolic content and other antioxidant properties of medicinal caterpillar fungus *Cordyceps militaris* on exposure to UV-B rays was reported by Huang et al (2015).

***In-vitro* protein digestibility:** There was a significant increase in *in-vitro* protein digestibility of button and oyster mushrooms after exposure to UV-B radiations (Table 6). Previous studies have also reported an effect of irradiation on protein structure and digestibility. Li et al (2020) reported that due to irradiation solubility of proteins increased, increased the polyphenols and these directly affects the protein digestibility. Further freeze drying is an efficient processing method which retained the nutrients with least losses.

Shelf life of UV-B treated mushroom powder and its supplemented products: UV-B treated mushroom powder and its supplemented indigenous food product (*panjiri*) were stored in three different containers: zip lock polyethylene bags, plastic containers and glass containers for a period of 5 months at room temperature and its microbial analysis was done. Initially no microbial growth was observed in stored material till 90th day. The bacterial growth was initiated in stored mushroom powder at 105th day of storage period and with the increase in storage period the bacterial count increased consistently. The bacterial count of the stored button mushroom powder in glass container was significantly lower at 0.33×10^2 cfu/g in comparison of Zip lock Polyethylene Bag and Plastic container after 5 months of storage. There was significant effect of packaging material and time on bacteria count of treated button mushroom powder. The yeast and mold count of treated button mushroom powder stored in different containers was assessed for 150 days of storage period. Initially no yeast and mold growth was observed till 105th day of storage period. The yeast and mold count was initiated at 120th day of storage period. After storage period of 150 days the yeast and mold count was higher in zip lock polyethylene bag packaging (0.85×10^2 cfu/g) as compared to plastic container and glass container in UV treated button mushroom powder. There was significant effect of time on yeast and mold count. Thus the glass container is considered to be a better storage container as compared to other containers in terms of its yeast and mold count.

Similar results were observed for UV-B treated oyster mushroom powder stored in different containers. The bacterial count of zip lock polyethylene bag packaging was higher at 1.33×10^2 cfu/g than plastic container and glass container containing UV treated oyster mushroom powder. There was a significant effect of time on bacteria count. There was a significant increase of yeast and mold count during storage period. In UV treated oyster mushroom powder the fungi count was observed higher in zip lock polyethylene bag (1.18×10^2 cfu/g) as comparison of plastic container and glass container. There was a significant effect of packaging material and time on yeast and mold count of treated oyster mushroom powder. Thus can conclude that Glass container is the good material for storage as compared to zip lock polyethylene bag and plastic container as the fungi growth was found significantly higher in zip lock polyethylene bag followed by plastic containers. Thus, UV-B treated mushroom powder and its supplemented products could be safely stored in air tight glass containers at room temperature for a period of 5 months.

CONCLUSIONS

The study concluded that out of the three UV wavelengths used to irradiate button and oyster mushrooms, UV-B rays treatment at a distance of 60 cm for a duration of 30 min resulted in an enormous spike in Vitamin D_2 content in mushrooms. Further this enriched quality of vitamin D was retained in mushroom powder supplemented food products. The UV treatment of mushrooms enhanced its nutritional composition in terms of total phenols, *in vitro* protein quality

Table 6. Total phenols and *in vitro* protein digestibility in UV treated button and oyster mushroom powders and their supplemented products (on dry weight basis)

Treatment	Total phenols (mg/100g)	*In-vitro* protein digestibility
CBMP	386.67±0.64	74.33±0.57
TBMP	496.67±0.64	84.25±0.87
|t|-Value	121.250	17.775
p-Value	<0.0001	<0.0001
COMP	364.07±0.98	73.32±2.68
TOMP	421.11±0.64	83.27±0.87
|t|-Value	48.699	6.127
p-Value	<0.0001	<0.0001
Control *Panjiri*	58.89±0.64	75.94±1.05
Experimental *Panjiri* (10%TBMP)	144.44±0.64	79.75±0.58
|t|-Value	94.305	5.495
p-Value	<0.0001	0.005
Control *Panjiri*	58.89±0.64	74.33±0.57
Experimental *Panjiri* (15%TOMP)	91.11±0.64	83.27±0.78
|t|-Value	35.518	4.102
p-Value	<0.0001	0.015

See Table 3 for details

and fatty acid composition. There was a significant increase in protein, fibre and ash content, mineral like iron, copper, phosphorus, potassium, zinc and selenium; total phenols , *in vitro* protein digestibility and Vitamin D content in UV treated mushroom powder supplemented indigenous food products. Vitamin-D_2 enriched mushroom powder can be extensively used as a food based approach to combat the problem of vitamin-D deficiency, address micro nutrient deficiencies and help in building up the immunity in this pandemic situation.

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Effect of Broiler Breeders Age of ROSS 308 on Eggshell Conductance throughout Production Period

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Abstract: This experiment was conducted at University of Anbar during 2020-2021to observed the effect of aging of the broiler breeders on the gas conductance of the egg shell by observing the age of breeders for 11 weeks starting from the age of 28 up to 41 weeks. This study uses 120 hatching egg from broiler breeders fields of Ross 308 of Al-Manar company for poultry production in Diyala. There was significant increase in the weight of eggs at the age of 38 and 40, accompanied with a change in the measured gas conductance (G1) were decreased in the early age of the breeders (28-34 weeks) but increased in the age 36-41 weeks. The aging processes of the breeders lead to a decrease in the conductance constant (K) value, and the gas conductance of the egg shell and an increase in gas conductance efficiency.

Keywords: Conductance, Conductance constant, Permeability, Broiler breeder age, Eggshell

The age of broiler breeders Ross 308 affects the values of standard gas conductance for hatching eggshells due to the change occurred in the average of egg weight which affects the gas conductance of egg shell (Nasri et al a 2020) . Sahan et al (2020) observed that there is an increase in the gas conductance from 11.00 to 11.99 mg/day/torr at the ages of 28 and 40 weeks with egg weights of 57.43 and 58.11g, respectively. Wesam et al (2015) also observed change in gas conductance throughout the producing cycles of eggs and increased in the first half of the cycle then it became moderate and stable afterwards. Nangsuay et al (2016) did not notice any changes in the values of eggshell conductance for the eggs of the breeder flocks, young ones and old ones, which was 4.18 and 4.48 mg/hr/Kilopascal at the ages 29 and 54 weeks, respectively. Salamon (2020) reported change in gas conductance as the breeders grow older and this change is attributed to the change in the thickness of the shell and the cuticle layer, because the rate of fluid loss from the egg increases with the decrease in the thickness of the shell and cuticle layer because the total shell deposition after the first three months of the egg-laying period remains fairly constant while the eggs continue to increase in size resulting in a thinner shell (Gaulhanone et al 2012). The study was conceited to observed the effect of aging of the broiler breeders on the gas conductance of the egg shell.

MATERIAL AND METHODS

This experiment was conducted at University of Anbar during the period (November 20, 2020 to March 9, 2021) to show the effect of progress in breeders age on the values of gas conductance of the eggshell by following the age of breeders for 11 weeks and over 14 weeks from the age of 28 and until the age of 41 weeks.

Breeder flock: Eggs from Ross 308 broiler breeder flock were used at 28, 29, 30, 32, 33, 34, 36, 37, 38, 40 and 41 weeks of age.

Egg collection and storage: The 120 hatching eggs were collected from the fields of broiler breeders, ROSS 308, affiliated to Al-Manar Poultry Production Company, in, Jizan Al-Imam of Diyala Governorate and were distributed in the form of 90 eggs 10 eggs/age of 28-29-30-32-33-34-36-37-38 weeks and 30 eggs of ages 40-41 weeks. All eggs were numbered and got their weight recorded, then the eggs were placed inside the dryer at a temperature of 25°C for 5 days, while observing the changes occurring on eggs weight by weighing the eggs on a daily basis at 24.

Eggshell water vapor conductance: The conductance was measured at 25°C, according to Visschedijk (1982) by placing the eggs inside the dryer and adding white silica gel that absorbs humidity at the base of the dryer with a rate of 5 grams for each egg. The G_{H2O} (G1) (mL STPD/day/mm Hg) values of the eggs were calculated according to the procedures of Peebles and McDaniel (2004) and G_{H2O} (G3) (mL STPD/day/mm Hg) according to Ar et al (1974). G_{H2O} (G5) (mL STPD/day/mm Hg) of the eggs was estimated according Hoyt (1980) . The specific G_{H2O} (gH2O -g2 , g5 , g6) was adjusted to 100 g on egg weight basis (mg of H_2O/d/Torr/100

g) as per Ar et al (1974) and Ar and Rahn (1978) modified by Pulikanti et al (2012). The G_{H2O} conductance constants (K_{H2O}) of the eggs were calculated using the procedures suggested by Christensen et al (2011).

Statistical analysis: The analysis was done by using General Linear Model (GLM) procedure of statistical software package SAS version 9.1 (SAS 2004), P values less than 0.05, 0.01 and 0.001 were considered to be significant for the main effect and results as presented as mean/ SEM.

RESULTS AND DISCUSSION

There was significant increase in egg weight over a period of 14 weeks through a follow-up of 11 weeks of breeders' age (28 to 41 weeks), especially at the age of 38 and 40 weeks (62.08 and 67.25 g, respectively), where the weight of the egg increased at this age and was accompanied by a change in the measured gas conductance values (G1). This decreased at the beginning of breeders age (28 -34 weeks) (7.78 - 8.35 - 7.78 - 7.09 - 8.10 - 5.83 ml STPD /day/ mm Hg) but increased at the age of (36-41 weeks) (Table 1). Lukic et al (2020) and Nasri et al (2020) also observed the average weight increase of egg with the aging. This increase in the weight of the egg due to the increase in the weight of the yolk and albumin of egg. The progression in the age of the breeders also led to a significant decrease in the conductance constant (K) (egg gm /G1/day) (Table 2). The higher egg weight was due to greater the egg's ability to retain internal fluids so the daily loss constant is

decreased (Christensen et al 2005). The conductance constant depends in its calculation on the change in the weight of the egg (g) as a result of the water vapor lost by the egg. The progression in the age of the breeders also led to a significant decrease in permeability (μm/day/Torr/cm^2) as a result of the increase in egg weight and size, which leads to an increase in the surface area of the egg shell because the permeability reflects the conductance amount per square cm of surface area (Table 2). The gas conductance efficiency helps in setting a standard for the efficiency of the conductance. The progression in the age of the breeders led to a significant increase in the conductance efficiency which means that the conductance measured by the measurement method (G1) do not approach the conductance values calculated using the equation Ar (1974), which is symbolized by G3, and do not approach the conductance values calculated by the method of Hoyt equation (1980), which is symbolized by G5 because the measured method G1 was the most accurate in determining the gas conductance for each egg, based on the difference during five days in egg weight, temperatures and atmospheric pressure (Table 3). The calculated method G3 and G5 was based on the average weight of the egg, the differences in weights as a result of storage and the natural pressure rate at sea level are not included in the calculation. The same results were achieved when calculating the gas conductance values for g2, g4 and g6 by returning the egg weight per 100 gm (Table 1).

Table 1. Gas conductance characteristics of hatching eggs shells during 14 weeks of breeders' age spanning from 28 to 41 weeks at 25ºC inside the desiccator

Breeder age (week)[1]	Egg weight (gm)[2]	G1	G2	G3	G4	G5	G6
28	54.66 [c]	7.78 [b]	14.26[bc]	12.18 [c]	22.28 [a]	12.96 [c]	23.72 [a]
29	56.02 [c]	8.35 [b]	14.90 [bc]	12.41 [c]	22.15 [a]	13.23 [c]	23.61 [a]
30	55.61 [c]	7.78 [b]	14.00[bc]	12.34 [c]	22.19 [a]	13.15 [c]	23.64 [a]
32	54.85 [c]	7.09[bc]	12.94[cd]	12.21 [c]	22.26 [a]	13.00 [c]	23.70 [a]
33	56.54 [c]	8.10 [b]	14.32[bc]	12.50 [c]	22.11 [a]	13.33 [c]	23.58 [a]
34	55.04 [c]	5.83[cd]	10.58[de]	12.24 [c]	22.24 [a]	13.04 [c]	23.69 [a]
36	54.51 [c]	11.38[a]	20.95 [a]	12.15 [c]	22.29 [a]	12.93 [c]	23.72 [a]
37	55.98 [c]	8.66 [b]	15.46[bc]	12.40 [c]	22.16 [a]	13.22 [c]	23.62 [a]
38	62.08 [ab]	10.62[a]	17.04 [b]	13.45[ab]	21.66[bc]	14.40[ab]	23.20[bc]
40	67.25 [a]	4.30 [d]	6.53 [f]	14.29 [a]	21.35 [c]	15.37 [a]	22.94 [c]
41	57.64 [bc]	4.44 [d]	7.71 [ef]	12.69b[c]	22.02[ab]	13.54[bc]	23.50[ab]
Probability	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Average	58.00	6.83	11.91	12.74	22.01	13.61	23.50
SEM	0.6396	0.2553	0.4749	0.1074	0.0476	0.1224	0.0397

[1] Broiler Breeder flock at 28, 29, 30, 32, 33, 34, 36, 37, 38, 40 and 41 weeks of age.
[2] Egg weight during breeder age from 28 to 41 weeks.

Table 2. Characteristics of gas conductance constant, permeability, and conductance efficiency of hatching eggshells during 14 weeks of breeders' age panning from 28 to 41 weeks at 25ºC inside the desiccator

Breeder age (week)[1]	Egg weight (gm)[2]	Conductance constant (G1/day/Egg gm)	Permeability µm/day/Torr/cm²))	Conductance[1] efficiency	Conductance[2] efficiency
28	54.66 [c]	0.712 [bc]	114.00 [c]	58.80 [bc]	69.06 [bc]
29	56.02 [c]	0.746 [bc]	120.22 [bc]	52.02 [bc]	62.03 [bc]
30	55.61 [c]	0.700 [bc]	112.60 [c]	60.46 [bc]	70.96 [bc]
32	54.85 [c]	0.648 [cd]	103.61 [cd]	73.21 [bc]	84.42 [bc]
33	56.54 [c]	0.714 [bc]	115.92 [c]	65.47 [bc]	76.44 [bc]
34	55.04 [c]	0.527 [de]	84.85 [d]	112.46 [b]	126.24 [b]
36	54.51 [c]	1.046 [a]	167.20 [a]	6.69 [c]	13.54 [c]
37	55.98 [c]	0.770 [bc]	124.74 [bc]	44.85 [bc]	54.37 [bc]
38	62.08 [ab]	0.853 [b]	142.48 [b]	31.68 [bc]	41.02 [bc]
40	67.25 [a]	0.326 [f]	55.51 [f]	278.43 [a]	306.88 [a]
41	57.64 [bc]	0.385 [ef]	62.75 [ef]	204.16 [a]	224.63 [a]
Probability	0.0001	0.0001	0.0001	0.0001	0.0001
General average	58.00	0.595	96.51	122.02	137.28
SEM	0.6396	0.0237	3.7576	12.0975	13.0259

[1] Broiler Breeder flock at 28, 29, 30, 32, 33, 34, 36, 37, 38, 40 and 41 weeks of age.
[2] Egg weight during breeder age from 28 to 41 weeks.

Table 3. Standard conductance characteristics of hatching eggshells measured by desiccator during 14 weeks from 28 to 41 weeks of age

Breeder age (week)	Egg weight (gm)	Average difference in weight loss for 96 hours (mg water vapor/day)	Average temperature (Celsius)	Temperature × Atmospheric pressure (Appendix)	Atmospheric pressure rate (torr)
28	54.67	144.13	24.35	22.922	763.863
29	56.02	152.97	24.14	22.648	764.463
30	55.61	143.70	24.45	22.922	761.463
Average	55.43	146.93	24.31	22.831	763.263
32	54.85	135.12	25.02	23.476	766.563
33	56.54	154.29	24.96	23.198	768.063
34	55.45	110.92	25.00	23.756	762.063
Average	55.48	133.44	24.99	23.477	765.563
36	54.51	216.67	25.00	23.756	765.513
37	55.98	165.00	25.00	23.756	765.630
38	62.08	202.22	25.00	23.756	763.863
Average	57.52	194.63	25.00	23.756	765.002
40	67.25	81.96	25.50	24.617	759.062
41	57.64	215.26	25.60	24.617	757.712
Average	62.445	148.61	25.55	24.617	758.387

CONCLUSION

The qualities and characteristics of gas conductance of the egg shell represented by conductance, conductance constant, conductance efficiency and gas permeability change according to the ages of broiler breeders due to the aging process and the change of egg production cycle.

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