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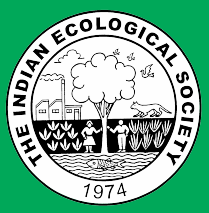

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Impact of Land Configurations and Integrated Nutrient Management Practices on Root Properties, Yield, NPK uptake of *Bt* cotton and Fertility Status of Soil

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Abstract: A field experiment was carried out to find the impact of different land configurations and integrated nutrient management practices on root properties, yield, NPK uptake of *Bt* cotton and fertility status of the soil at Professor Jayashankar Telangana State Agricultural University, Hyderabad. The yield attributes (bolls per plant and boll weight) and seed cotton yield were significantly higher with BBF laid with poly mulch in addition with application of 100% RDF + 25% RDN through organics (pressmud or FYM), which was comparable to Broad Bed Furrow laid with poly mulch and application of 125% RDF through inorganics. Similarly, among the land configuration treatments, Poly mulch on broad bed has recorded higher root yield, root volume, NPK uptake and post-harvest status of soil such as organic carbon (%) and available soil NPK respectively. Application of 100% RDF + 25 % RDN through Pressmud has recorded highest yield and yield attributes, root weight and volume, NPK uptake and available NPK status in the soil which was at par with 100% RDF + FYM equivalent to 25 % RDN and 125% RDF alone among the nutrient management practices. Based on the results, poly mulch on broad bed in combination with either pressmud or FYM or application of 125% RDF alone can be well recommended to farmers of Telangana.

Keywords: Bt cotton, Poly mulch, Ridge and furrow, Broad bed and furrow, FYM and pressmud, INM and field water use efficiency

Cotton is a member of the Malvaceae family and is primarily farmed in tropical and subtropical regions. The objective of cotton development programmes around the world has always been to combine high yield and high-quality fiber in order to meet the needs of growers and industry (Mudhalvan et al 2021). Fertilizer makes up 20–30% of the cost of producing cotton, which has high nutritional requirements. However, there isn't much information in the literature about cotton's dietary needs, particularly for recently developed varieties. To achieve high yields, lower production costs per ton, and boost the financial viability of the production system, cotton must receive adequate nutrition (Vieira et al 2018).

Currently India has topped in area with 11.88 m ha^{-1}covering 30 per cent of World coverage and 22 per cent (351 lakh bales of lint) of the world cotton production with a productivity of 568 kg ha^{-1} (Directorate of Cotton Development, 2017). The productivity of cotton is significantly lower (568 kg ha^{-1}) as compared to the four major cotton growing countries *i.e.,* China (1300 kg ha^{-1}), USA (900 kg ha^{-1}), Pakistan (700 kg ha^{-1}) and Brazil (673 kg ha^{-1}).

Black soils are ideal for growing cotton, yet in our nation, more than 65% of cotton is cultivated on red soil. Along with assuring superior stand, establishment, uniform growth, fertilizer use efficiency, and yield under rainfed conditions, correct land configuration according to the soil type also helps to conserve soil moisture effectively (Kumari et al 2018). In dryland agriculture, the evapotranspiration needs of crops are not only not met by the amount of rainfall, but also by how it is distributed. Moisture conservation is the main issue in dry land farming. In situ rainwater conservation is therefore necessary. For the purpose of achieving sustainable yields, effective rain water management and in-situ moisture conservation, such as opening furrows, intercropping, mulching, etc., are essential (Gokhale et al 2012). Mulch specifically prevented the movement of water vapor from the soil surface to the microclimate, which reduced the direct evaporative loss of soil water and enhanced the soil's availability to the crops (Xie et al 2006, Fuchs and Hadas 2011). Utilizing plastic mulch has demonstrated water savings in cotton of between 40 and 50 percent (Nalayani et al 2009).

Farmers are not using fertilizers at the recommended rates, which causes an imbalance between the supply of nutrients and the demand from crops (Karthiket al 2022, Dhaker et al 2022). One of the main causes of low cotton output is the unbalanced use of fertilizers, which has led to soil productivity issues and micronutrient shortages. To

achieve higher yields and maintain soil health, an integrated application of chemical fertilizers and organic manures is required. Due to the low or nonexistent maintenance of the cattle population on the farm, organic sources with high nutrient content, such as Pressmud, may be a better option given the limited availability of FYM (Ghulam et al 2012).In light of the aforementioned facts, this study was conducted to determine the effects of various soil moisture conservation strategies and integrated nutrient management approaches on the root characteristics, productivity, NPK uptake of *Bt cotton* and post-harvest fertility status of red soil in Telangana.

MATERIAL AND METHODS

A field experiment was conducted during *kharif* 2015 and 2016 at College farm, College of Agriculture, Rajendranagar, Professor Jayashankar Telangana State Agricultural University, Hyderabad situated at an altitude of 542 m above mean sea level at 17°19' N latitude, 78°23' E longitude under rainfed conditions. The soil of the experimental site was sandy loam with soil pH of 7.33, low available N (182 kg ha^{-1}), medium in P_2O_5 (46.8 kg ha^{-1}) and high in K_2O (432 kg ha^{-1}). The experiment was laid out in strip plot design with three replications. The size of gross and net plots were7.2 m x 5.4 m and 5.4 m x 4.2 m respectively. There were twenty treatments with combinations of four *in-situ* moisture conservation practices (main plots)*viz.,* flat method (M_1), ridge and furrow (M_2), BBF (M_3) and poly mulch on BBF (M_4) as main plots and five integrated nutrient management (INM) practices as sub plots i.e., Farmer's practice (S_1), 100% recommended dose of fertilizers (RDF, S_2), 125% RDF (S_3), 100% RDF along with 25% N through FYM (S_4) and 100% RDF along with 25% RDN through press mud (S_5). Bt hybrid Neeraja BT-II seeds were dibbled @ 1 seed $hill^{-1}$ on 7th July during 2015 and 2nd July during 2016. The recommended dose of fertilizers to cotton in Telangana state was 150:60:60 NPK kg ha^{-1}.Entire P fertilizer was applied as basal and N and K applied at 20, 40, 60 and 80 days after sowing (DAS) in equal splits. In integrated nutrient management treatments (S_4sand S_5), 25 per cent nitrogen was applied through organic manures as basal and remaining as that of recommended dose of fertilizers (100% RDF). Farmers practice of nutrient management was decided after survey of nutrient management in 30 cotton growing farmers fields in Telangana. Farmers are applying 50 kg of DAP at 20-25 DAS, 50 kg of 14-35-14 at 40-45 DAS, 50 kg of urea and 25 kg of muriate of potash at 60-65 DAS, 75 kg urea and 25 kg potash at 80-100 DAS. Based on the above, farmers practice of nutrient management was 3.75 t FYM ha^{-1}, 184-101-92kg N, $P_2O_5$and K_2O ha^{-1}followed.

Pressmud contains 1.92and 2.24 percent nitrogen during 2015 and 2016. FYM contains 0.49 and0.72% during 2015 and 2016. After laying land configurations, during 2015, 1953 kg of pressmud and 7653 kg of FYM were applied in S_5 and S_4 treatment plots. During 2016, 1674 kg of pressmud and 5208 kg of FYM were applied in S_5 and S_4 treatments. In M_1 treatment, simple flat bed method of sowing was imposed without any soil moisture conservation treatments as check. In M_2 treatment, ridges and furrows were laid at 90 cm apart respectively. While in M_3 sand M_4 broad bed and furrow treatment, beds of 120 cm width and furrows of 60 cm were laid. In M_4 treatment**,** polythene mulch with black (upper) and grey (bottom) having 25 µ thickness was laid before sowing of the crop on the raised (broad) beds (120cm). Before laying the film, small circular holes were made as per the intra row spacing (60 cm) of the crop and the sheet was spread on the raised bed. After that, the sides of the polythene film were covered within the soil. Under all the treatments, sowing was done by adopting intra row spacing of 60 cm, thus maintained uniform plant population (18,519 plants ha^{-1}). A total rainfall of 375.3 mm was received in 27 rainy days during 2015-16 and 741.1 mm in 37 rainy days during 2016-17, against the decennial average of 616 mm received in 37 rainy days. The crop was sprayed with monocrotophos @ 1 ml l^{-1} against aphids and bollworms and drenching of carbendazim @ 1g l^{-1} of water against wilt. The crop was finally terminated on 10th December during 2015 and 6th December during 2016. Statistical analysis of the data of various yield attributes, root properties, yield, NPK uptake studied were carried out

RESULTS AND DISCUSSION

All the parameters like the number of bolls produced per plant, boll weight, cotton seed and stalk yield, root weight, root volume, NPK uptake of cotton was significantly affected by moisture conservation practices and integrated nutrient management practices during both the years of study. The interaction effect was also significant among all parameters.

Number of bolls plant^{-1}: Number of bolls $plant^{-1}$ were significantly higher in poly mulch on broad bed (M_4) (28.7). Pooled data analysis indicated that, the mean increase in number of bolls per plant under poly mulch on broad bed (28.7) was 38.6, 21.6 and 12.5 per cent over flat bed (M_1), broad bed sand furrow (M_3) and ridge sand furrow (M_2) methods, respectively (Table 1). The increase in the number of bolls $plant^{-1}$in mulched plot was probably associated with the conservation of moisture and favorable micro climate which in turn provided a favorable conditions towards higher dry matter accumulation and greater number of leaves and fruit bearing nodes as compared to the rest of the moisture conservation treatments. Ridge and furrow (M_2) method was

on par with M_4 and recorded significantly higher number of bolls as compared to broad bed sand furrow and flatbed methods during both the years of experimentation. Pooled data analysis indicated that, the mean increase in number of bolls under ridge sand furrow (25.5) was 23.1 and 8.0 per cent over flat bed and broad bed and furrow methods. This might be due to the higher amount of moisture conserved in ridge and furrow as compared to flat bed sowing and broad bed methods. Broad bed and furrow method recorded significantly higher number of bolls compared to flat bed method during both the years. Pooled data analysis indicated that, the mean yield advantage under broad bed sand furrow (23.6) was 14.0 per cent over flat bed method. Increase in the number of sympodial branches and squares per plant lead to the increase in the number of bolls per plant. Significantly higher number of bolls were recorded in S_5 (100% RDF + 25% RDN through pressmud). Pressmud after decomposition releases major and micro nutrients, which become available throughout crop growth period that lead to more number of bolls per plant.S_5 treatment was on par with (S_4) 100% RDF + 25% RDN through FYM (26.0). The higher number of bolls in combined application of 100 % RDF and 25% RDN through FYM could be due to continuous supply of nutrients from FYM to the plant. Inbuilt resistance to boll worms and early maturing character was observed in case of *Bt* hybrid which helped to retain more number of bolls by avoiding its exposure to unfavourable weather condition during peak period of growth that may commence probably during later stages. Hence, application of 100% RDF along with 25% RDN through FYM showed marked effect on number of bolls per plant. These results are in conformation with the findings of Jagdish Kumar and Yadav (2010). Application of 100% RDF + 25% RDN through FYM (S_4) was on par with (S_3) 125% RDF (25.4) followed by (S_1) farmers' practice (23.3) and (S_2) 100% RDF (21.8). The application of 125% RDF over 100% RDF resulted in efficient translocation of photosynthates due to adequate amount of available nutrients that favored higher number of bolls and boll weight. Singh et al (2003) reported that 125% RDF resulted in significantly higher yield as compared with RDF alone. Interaction between soil moisture conservation practices and integrated nutrient management practices was found to be significant. Significantly higher number of bolls were recorded with application of poly mulch on broad bed and application of 100% RDF along with 25% RDN through pressmud (M_4S_5) recorded significantly highest mean number of bolls (30.3) and poly mulch on broad bed and application of 100% RDF along with 25% RDN through FYM (30.1). M_4S_4 treatment was in par with poly mulch on broad bed and application of 125% RDF (M_4S_3) indicating that poly mulch on broad bed was comparatively more effective when RDF applied along with either pressmud or FYM. More retention of soil moisture and continuous supply of nutrients in these treatments resulted in higher number of bolls in *Bt* cotton hybrid and it might have got the full advantage of available soil moisture and nutrient management during boll development stage.

Boll weight (g): Perusal of data indicated significant effect of moisture conservation treatments on boll weight of *Bt* cotton hybrid. During both the years, poly mulch on broad bed method recorded significantly higher boll weight (6.0 g) compared to rest of the moisture conservation treatments (Table 1). The poly mulched cotton had significantly produced heavier bolls against other land configurations. This might be due to better partitioning of assimilates under mulching, due to conservation of soil moisture, restricted weed growth and increased soil temperature under mulched treatment. The next best treatment was ridge and furrow method (M_2) which recorded significantly higher boll weight (5.6 g) as compared to broad bed sand furrow and flatbed methods during both the years. This might be due to the reason that ridge and furrow reduces the runoff and thus

Table 1. Effect of land configurations and nutrient management practices on bolls per plant and boll weight of Bt cotton (Pooled data)

Treatments	No. of bolls per plant						Boll weight (g)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1– Flatbed (control)	19.7	17.6	21.3	22.0	23.0	20.7	4.7	4.3	4.8	4.8	4.6	4.7
M_2– Ridge sand furrow	24.1	22.9	26.2	27.0	27.5	25.5	5.2	5.0	5.7	5.8	5.9	5.6
M_3– BBF	22.0	20.9	24.3	25.0	25.7	23.6	4.9	4.8	5.2	5.4	5.9	5.2
M_4– Poly mulch on BBF	27.5	26.0	29.9	30.1	30.3	28.7	5.9	5.5	6.0	6.0	6.2	6.0
Mean	23.3	21.8	25.4	26.0	26.6	24.6	5.2	4.9	5.5	5.5	5.6	5.3
C.D at 5%		1.4	0.7	0.4	1.5			0.3	0.3	0.4	0.5	
CV		7.5						7.9				

Sub treatments (S) S_1: Farmers practice, S_2: 100% RDF, S_3 : 125% RDF, S_4 : 100% RDF + FYM equivalent to 25% RDN , S_5: 100% RDF + Pressmud equivalent to 25% RDN

provides more opportunity time for infiltration. Adequate soil moisture conservation through opening of furrow after each row resulted in higher boll weight and more seed cotton yield plant^{-1} especially in rainfed cotton zone. (Narkhede et al 2015). Pooled data analysis indicated that broad bed sand furrow method (M_3) recorded significantly higher boll weight (5.2 g) compared to flatbed method. Lower boll weight under flat bed method might be due to lower availability of water and nutrients, thereby reduced LAI and crop dry matter that lead to poor portioning of resource to sink (bolls). The boll weight of *Bt* cotton hybrid was significantly affected by different integrated nutrient management practices. Significantly higher boll weight (5.6 g) was recorded with application of (S_5) 100% RDF + 25% RDN through pressmud treatment. This could be due to increased availability of N, P, K, Ca, Mg and S through pressmud application. Kalaivanam and Omar Hattab (2008) reported that addition of pressmud increased the availability of nutrients and their uptake in rice and wheat crops. S_5 treatment was on par with 100% RDF + 25 % RDN through FYM (5.5 g) and 125% RDF (5.5 g). Significantly higher boll weight in treatments consisting of combined application of RDF and organics could be due to favorable effect in improving soil physical properties and better nutrient supply throughout the crop growth. Hence, application of RDF along with pressmud or FYM showed marked effect on yield attributes of cotton. Higher boll weight might be due to production of higher number of monopodial and sympodial branches and thereby larger bolls that lead to higher accumulation of photosynthates in reproductive parts. Similar finding in cotton was earlier reported by Mehta et al (2009). The treatment consisting of application of 125% RDF was comparable with (S_1) Farmers practice (5.2 g) and S_1 was in turn on par with (S_2) 100% RDF (4.9 g). Higher boll weight under 125 % RDF could be ascribed to the improved LAI and drymatter production. Thus, higher photosynthetic activity with adequate nitrogen fertilization enabled the plant to accumulate more drymatter and greater translocation of photosynthates to the developing boll resulting in higher number of seeds per boll that reflected in larger bolls. Interaction between treatment combination involving poly mulch on broad bed and application of RDF along with 25 % RDN through pressmud (M_4S_5) recorded significantly highest boll weight (6.2 g). This treatment was on par with (M_4S_4) poly mulch on broad bed and application of RDF along with 25 % RDN through FYM (6.0 g). These two treatments were in turn on par with M_4S_3, M_4S_1, M_2S_5 and M_3S_5 indicating that poly mulch on broad bed was on par with broad bed and ridge and furrow method of sowing along with 100 % RDF + pressmud equivalent to 25% RDN.

Seed cotton yield (kg ha^{-1}): There was significant effect of moisture conservation treatments on seed cotton yield. During both the years, poly mulch on broad bed method was superior over other treatments and recorded significantly higher seed cotton yield (Table 2). Pooled data analysis indicated that, the mean yield advantage under poly mulch on broad bed (2183 kg ha^{-1}) was to the tune of 31.34, 19.74 and 8.66 per cent respectively over flat bed, broad bed sand furrow and ridge sand furrow methods. The highest yield under poly mulch on broad bed method was due to conservation of soil moisture, restricted weed growth and increase in the soil temperature there by preventing the loss of nutrients and favorable soil micro climate congenial for better growth and development of the crop. Increasing the number of monopodial and sympodial branches per plant lead to the increase in the number of bolls per plant consequently higher seed cotton yield per plant. The present results are in conformity with Hugar and Halemani (2010) who also reported improved seed cotton yield under polyethylene mulch to the extent of 11 to 27 per cent as compared to no mulch. The treatment Poly mulch on broad bed was followed by ridge and furrow, that recorded significantly higher seed cotton yield over broad bed sand furrow and flat bed methods during both the years. Pooled data analysis indicated that, the mean yield advantage under

Table 2. Effect of land configurations and nutrient management practices on Seed cotton yield (kg ha^{-1}) of Bt cotton (Pooled data)

Treatments	S_1	S_2	S_3	S_4	S_5	Mean
M_1– Flatbed (Control)	1566	1447	1695	1758	1843	1662
M_2– Ridge sand furrow	1871	1779	2076	2125	2195	2009
M_3– BBF	1687	1590	1898	1938	2004	1823
M_4– Poly mulch on BBF	2018	1888	2293	2346	2370	2183
Mean	1785	1676	1990	2042	2103	1919
C.D at 5%		89	68	53	100	
CV		7.2				

ridge sand furrow (2009 kg ha^{-1}) was to the extent of 20.87 and 10.2 per cent over flat bed and broad bed sand furrow methods. This might be due to the reduced runoff under ridge and furrow method that provided more opportunity time for infiltration. Ambikaet al(2017) reported that ridge and furrow method of planting recorded significantly higher leaf area, total drymatter production, seed cotton yield and harvest index over flatbed. Broad bed sand furrow method recorded significantly higher seed cotton yield compared to flat bed method during both the years. The mean yield advantage under broad bed sand furrow (1823 kg ha^{-1}) was 9.68 per cent over flat bed method. The increased seed cotton yield was due to improved yield components i.e., number of squares, number of bolls $plant^{-1}$, mean boll weight and seed cotton yield $plant^{-1}$ (Table 1 and 2). In broad bed and furrow system, there was an advantage of draining excess water around the plant during high rainfall events such as, at 60- 90 DAS stage during the year 2015 or 16. BBF aids in better moisture conservation over flat bed method during moisture stress period during boll development stage. The lower yield in flatbed method was due to reduced number of squares, number of bolls $plant^{-1}$, mean boll weight and seed cotton yield $plant^{-1}$. The yield of *Bt* cotton was significantly influenced by integrated nutrient management practices. Significantly higher seed cotton yield (2103 kg ha^{-1}) was recorded in 100% RDF + 25% RDN through pressmud (S_5) treatment. The higher seed cotton yield with different INM practices may be attributed to the various yield components *viz*., number of good and bad opened bolls per plant, number of squares per plant, number of bolls per plant, boll weight. The use of organic manures like pressmud or FYM increases the microbial activity which in turn helps in solubilization of nutrients making them more available to plants. Kumar et al (2017) reported that application of 20 t/ha pressmud and addition of NPK equivalent to 75% of recommended dose to each crop through fertilizers were found to be beneficial and resulted 21-43% higher crop yield. Sugarcane filter cake or pressmud is valued as a soil amendment and an important source of crop nutrients. It is a source of replenishing nutrients in the soil either alone or in combination with fertilizer to subsidize the input costs. Similar results were earlier reported by Raut et al (2008). The treatment (S_4) consisting of application of 100% RDF + 25% RDN through FYM (2042 kg ha^{-1}) was at par with S_5 treatment. The higher seed cotton yield in treatments consisting of integration of organics and inorganics was due to their beneficial effect in improving soil physical characters and supply of nutrients throughout the crop growth period. Hence, application of RDF along with pressmud or FYM showed marked effect on seed cotton yield. This could be attributed to the effect of applied fertilizer and mineralization of organic sources or through solublization of the nutrients from the native sources during the process of decomposition. These results are in conformity with those of Solunke et al (2011) and Tayade et al (2012). Application of 100% RDF + 25% RDN through FYM (S_4) was in turn on par with 125% RDF (1990 kg ha^{-1}) followed by (S_1) Farmers practice (1785 kg ha^{-1}) and (S_2) 100% RDF (1676 kg ha^{-1}). Higher seed cotton yield under 125% RDF over 100% RDF was due to the efficient translocation of photosynthates due to adequate amount of available nutrients that favored higher number of bolls and boll weight thus reflecting in higher seed cotton yield. These results are in accordance with those of Kalaichelvi (2009) who reported significantly higher yields with125% RDF as compared to RDF alone.

Interaction between treatment combination involving poly mulch on broad bed and application of 100% RDF along with 25% RDN through pressmud (M_4S_5) recorded significantly higher (63.8 %) mean seed cotton yield (2370 kg ha^{-1}) over flat bed along with application of 100% RDF (M_1S_2). This treatment was comparable with (M_4S_4) poly mulch on broad bed and application of 100% RDF along with 25% RDN through FYM (2346 kg ha^{-1}). M_4S_5 and M_4S_4 treatments were in turn on par with poly mulch on broad bed and application of 125% RDF (M_4S_3) indicating that poly mulch on broad bed was more effective when RDF applied along with pressmud or FYM or 125% RDF alone. Increased seed cotton yield under broad bed and furrow with poly mulch was due to the sufficient soil moisture in the root zone and minimized evaporation loss due to mulching. The extended retention of moisture lead to higher uptake of nutrients for proper growth and development of plant which resulted in higher yield as compared to control. Organic manures increased organic matter and improved the physical, chemical and biological properties of the soil after decomposition, thus improved plant growth and development reflecting in higher yields. These results are in accordance with those of Patel et al (2015), who reported that increase in the seed cotton yield with application of pressmud, FYM and higher fertilizer (125% RDF) might be due to significantly higher growth parameters and higher drymatter accumulation in reproductive parts. Utilization of more photosynthates for the nourishment to bolls favoring reproductive growth could be the key physiological phenomenon in *Bt* cotton that resulted into more seed cotton yield.

Root Properties

Root weight (g): There was significant effect of moisture conservation treatments on root weight. Poly mulch on broad bed method recorded significantly higher root weight during both the years as compared to rest of the moisture

conservation treatments (Fig. 1). The higher root weight under poly mulch on broad bed was 12.4 g and was 37.7, 19.2 and 12.7 per cent over flat bed, broad bed sand furrow and ridge sand furrow methods respectively. Increased root weight in poly mulch was due to increased root length of primary and secondary roots. The enhanced root growth under mulching might be due to enhanced root proliferation due to higher moisture and moderate temperature. The next best treatment was ridge and furrow, which recorded significantly higher root weight as compared to broad bed sand furrow and flat bed methods during both the years. Pooled data analysis indicated that, the mean increase in root weight under ridge sand furrow was 11.0 g and was 22.2 and 5.76 per cent higher over flat bed and broad bed sand furrow methods. This might be due to proper drainage of excess rain water thus maintained optimum moisture availability to the plants (Thakur et al 2011). Broad bed sand furrow method recorded significantly higher root weight compared to flat bed method during both the years. The root weight under broad bed sand furrow was 10.4 g and was 15.5 per cent higher over flat bed method. The increased root weight was due to decrease in the evaporation rate and availability of more soil water in profile for a longer period which facilitated better root growth. Increased soil moisture tension in flat bed method, exerts a physiological effect on the roots elongation, turgidity consequently the number of root hairs decrease with increasing tension.

Integrated nutrient management practices also significantly influenced the root weight of *Bt* cotton. Significantly higher root weight (11.6 g) was recorded with application of (S_5) 100% RDF + 25% RDN through pressmud treatment (Fig. 1). Pressmud is rich in beneficial microorganisms such as which aid in mineralization of plant nutrients in the soil and make them available to the plant roots. These microbes produce enzymes, auxins and other growth regulators, amino acids and many other organic acids which help in the proliferation of the root hairs and lateral roots of the tap root/fibrous root system. Next to this, application of 100% RDF + 25% RDN through FYM produced higher root dry weight (11.3 g). This may be ascribed to the improvement in the soil physico-chemical and biological properties due to the incorporation of organics along with 50 per cent recommended dose of fertilizers which might have hastened the nutrient availability as well as better soil conditions for root penetration. These results are in close agreement with the findings reported by Allam et al (2022). It was followed by application of 125% RDF (11.0 g), (S_1) Farmers practice (10.2 g) and (S_2) 100% RDF (9.4 g), respectively. This might be due to the higher and continuous nutrient availability from combined source up to the maturity that would have increased the overall growth of the plant including root.

Interaction between soil moisture conservation practices and integrated nutrient management practices were found to be significant during both the years of experimentation and in pooled results. Treatment combination involving poly mulch on broad bed and application of RDF along with 25% RDN through pressmud (M_4S_5) recorded significantly highest mean root weight (13.3 g). This treatment was on par with (M_4S_4) poly mulch on broad bed and application of RDF along with 25% RDN through FYM (12.9) followed by (M_4S_3) 125 % RDF. Thus, indicating that poly mulch on broad bed was comparatively more effective when RDF was applied either with pressmud or FYM.

Root volume: The root volume of *Bt* cotton was significantly affected by moisture conservation treatments. Poly mulch on broad bed method recorded significantly higher root volume during both the years as compared to rest of the moisture conservation treatments (Fig. 2). Pooled data analysis indicated that, the mean increase in root volume under poly mulch on broad bed (49.5) was 35.9, 21.6 and 13.2 per cent higher over flat bed, broad bed sand furrow and ridge sand furrow methods respectively. Maintaining high soil moisture content or higher water potential in Poly mulch on broad bed continuously favor better root development to a greater depth vertically and horizontal distance thereby coming in contact larger soil mass which enable the plants to absorb higher amount of moisture and nutrients. The enhancement in root length, secondary roots and root weight has been reflected in enhanced root volume. Halemani (2010) reported that mulching reduced the moisture loss by evaporation and there by conserved more amount of moisture in surface layer, reflecting in higher root growth. The ridge and furrow system followed M_5 and recorded significantly higher root volume as compared to broad bed sand furrow and flat bed methods during both the years. The mean increase in root volume under ridge sand furrow (43.7) was 20.0 and 7.3 per cent over flat bed and broad bed sand furrow methods. Broad bed sand furrow method recorded significantly higher root volume compared to flatbed method during both the years. The mean increase in root volume under broad bed sand furrow was 11.8 per cent higher over flatbed method. Integrated nutrient management practices also significantly influenced the root volume of *Bt* cotton. Significantly higher root volume (45.6) was recorded in (S_5)100% RDF + 25% RDN through pressmud treatment (Fig. 2). S_5 treatment was followed by (S_4) 100% RDF + 25% RDN through FYM (44.5). Significantly higher root volume may be attributed to FYM, which might have acted as a source of additional nutrients and moisture supply. Organics

are known to have a favourable effect on soil structure, tilth and thus, facilitate quick and greater availability of plant nutrients and thus provide a better environment for root growth and proliferation (Ambika et al 2017a). This could be ascribed to higher and continuous nutrient availability from combined source up to the maturity. Similar findings were documented by Singh et al (2020). 100% RDF + FYM (S_4) was followed by 125% RDF (43.1), (S_1) farmers practice (41.0) and (S_2) 100% RDF (38.6).Interaction between treatment combination involving poly mulch on broad bed and application of RDF along with pressmud (M_4S_5) recorded significantly higher root volume (53.0). This treatment was found on par with (M_4S_4) poly mulch on broad bed and application of RDF along with FYM (44.5). M_4S_5 and M_4S_4 treatments were in turn on par with poly mulch on broad bed and application of 125% RDF (M_4S_3) indicating that poly mulch on broad bed was comparatively more effective when RDF applied along with either pressmud or FYM or 125% RDF alone.

NPK Uptake

Nitrogen (N) uptake (kg ha^{-1}): Application of poly mulch on broad bed method (M_4) recorded significantly higher N uptake at flowering and at harvest during both the years compared to rest of the moisture conservation treatments (Fig. 3). The poly mulch on broad bed recorded higher N uptake (89.9 sand 141.8 kg ha^{-1}) over flat bed, broad bed sand furrow and ridge sand furrow methods. Higher uptake of nutrients in mulched treatment might be due to the enhanced soil moisture availability that resulted in more solubilization of nutrients that lead to adequate availability and uptake by plants. These results are in agreement with the findings of Alzamel et al (2022). The ridge and furrow treatment (84.5 sand 128.4 kg ha^{-1}) followed S_5 and was on par with broad bed sand furrow (80.9 sand 118.4 kg ha^{-1}). The N uptake recorded with broad bed sand furrow method was comparable with flatbed method (76.8 sand108.1 kg ha^{-1}). The increased N uptake might be due to the improved soil moisture, which in turn lead to the enhanced uptake of nutrients. Broad bed and furrow system also has the advantage of draining excess water around the plant thus facilitating adequate aeration. Raised bed system improved the uptake of moisture and nutrients resulting in better plant growth with production of

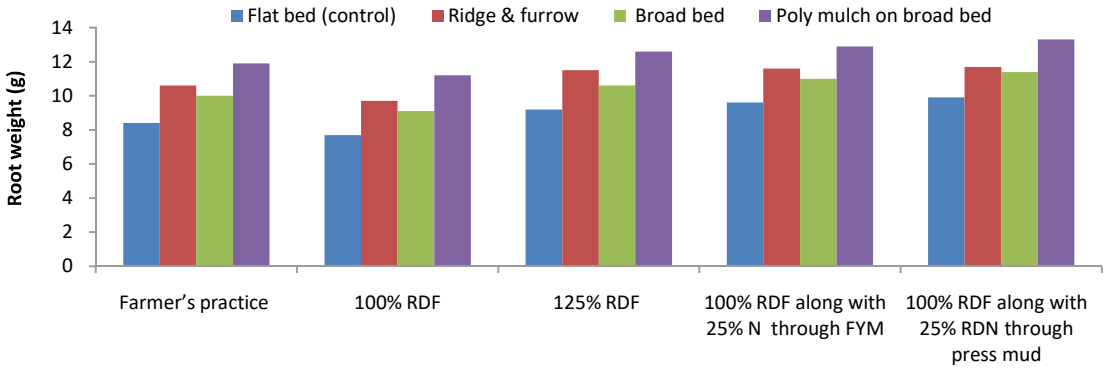

Fig. 1. Effect of moisture conservation practices and INM on root weight (g) of Bt cotton at 90 DAS

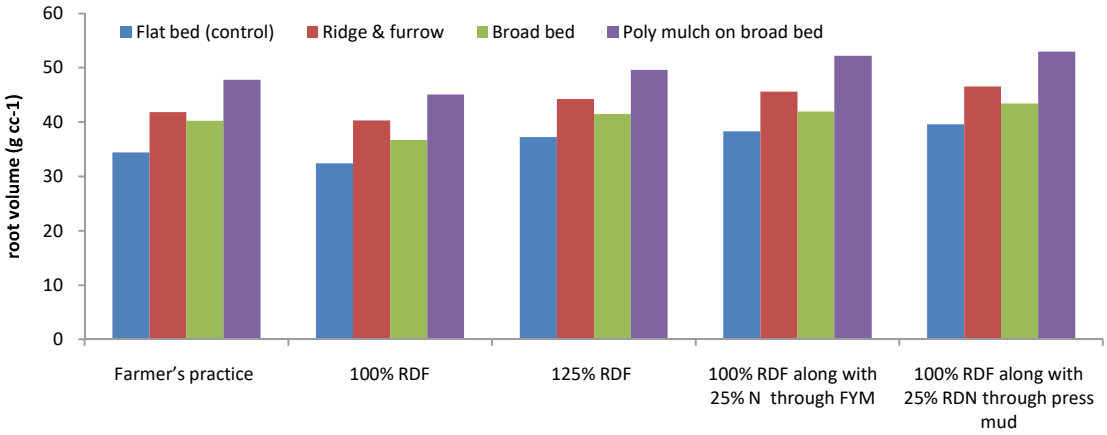

Fig. 2. Effect of moisture conservation practices and INM on root volume (g cc^{-1}) of *Bt* cotton at 90 DAS

higher dry matter plant^{-1} there by leads to higher uptake of nutrients.

Integrated nutrient management practices also significantly influenced the N uptake at flowering and at harvest (Fig. 3). Nitrogen uptake is the resultant of nutrient concentration and drymatter accumulation. Higher N uptake (85.6 sand 133.9 kg ha^{-1}) was recorded with 100% RDF + 25% RDN through pressmud equivalent to 25 % RDN (S_5). Rao et al (2005) have reported higher uptake of plant nutrients with the application of organic manures. Nutrient uptake invariably varies with nutrient content in the plant and dry biomass production as nutrient uptake is the product of drymatter and nutrient content. It could be observed from the data that except with 100% RDF, the nutrient removal by all the integrated nutrient management treatments was on par and supply of additional nutrients through organic fertilizers helped in uptake of more nutrients. Increased nitrogen uptake might be due to the direct addition of the N through pressmud and FYM and greater multiplication of soil microbes, which could convert organically bound N to inorganic form. Further, increased nitrogen uptake was also due to efficient root system with improved cell permeability coupled with better absorption due to better availability of nutrients in the soil solution (Sumathi and Rao., 2007). The interaction between soil moisture conservation practices and integrated nutrient management practices were significant on nitrogen uptake at flowering and at harvest. Treatment combination (M_4S_5) consisting of poly mulch on broad bed and application of RDF along with pressmud equivalent to 25% RDN recorded significantly highest N uptake at flowering (92.4 kg ha^{-1}) and at harvest (154.1 kg ha^{-1}). However, it was found on par with (M_4S_4) poly mulch on broad bed and application of 100% RDF along with FYM equivalent to 25 % RDN (92.0 kg ha^{-1}). M_4S_5 and M_4S_4 treatments were in turn on par with poly mulch on broad bed and (M_4S_3) application of 125% RDF indicating that poly mulch on broad bed was comparatively more effective when, RDF was applied either with pressmud or FYM equivalent to 25% RDN or 125% RDF alone. This might be due to the extended retention and availability of moisture coupled with higher drymatter production and nutrient content that resulted in higher N uptake as compared to corresponding lower level of fertilizer or inorganics alone.

Phosphorus (P) uptake (kg ha^{-1}): There was significant effect of moisture conservation treatments on P uptake at flowering and at harvest. Poly mulch on broad bed method (M_4) recorded significantly higher P uptake during both the years (Fig. 4). P uptake under poly mulch on broad bed (17.1 sand 28.4 kg ha^{-1}) was significantly higher over flat bed and broad bed sand furrow but it was comparable with ridge sand

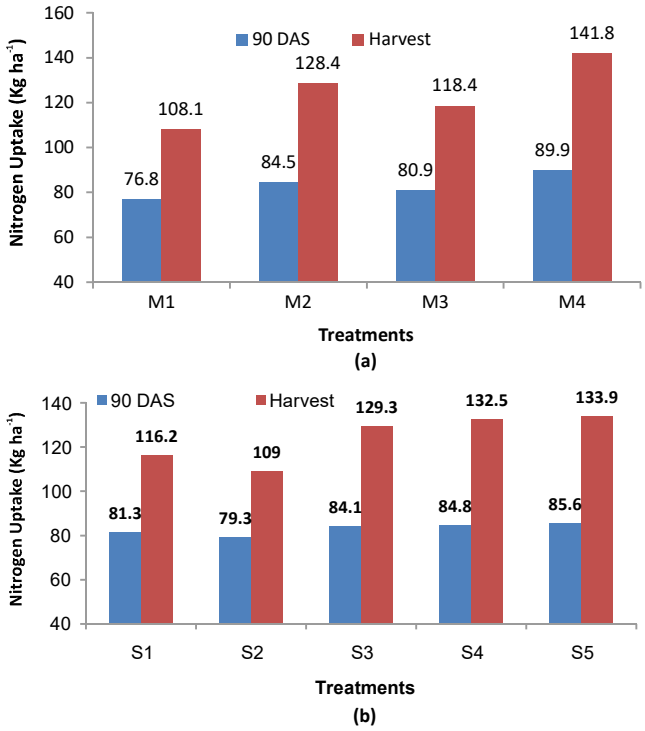

Fig. 3. Effect of (a) moisture conservation practices and (b) INM practices on Nitrogen (N) uptake (kg ha^{-1}) by *Bt* cotton at flowering and at harvest

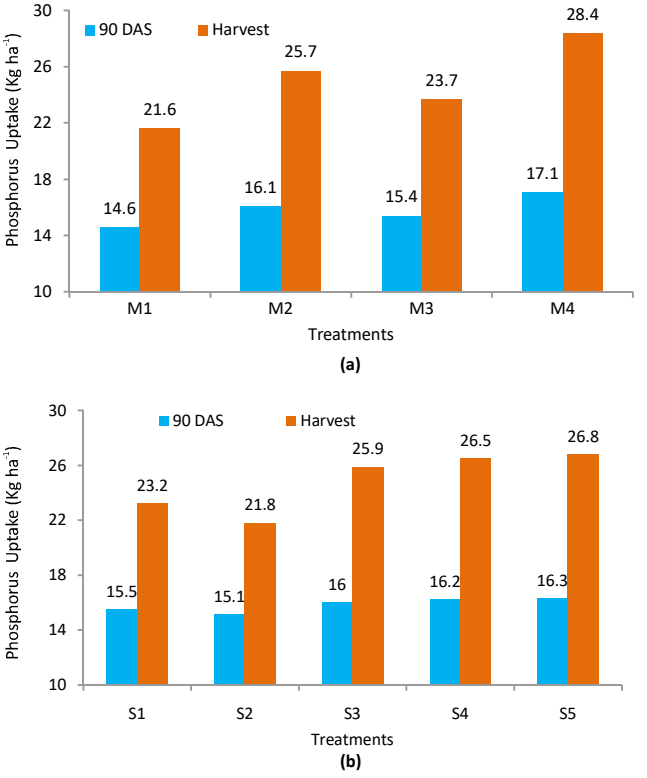

Fig. 4. Effect of (a) moisture conservation practices and (b) INM practices on phosphorus (P) uptake (kg ha^{-1}) by *Bt* cotton at flowering and at harvest

furrow method. Regulated temperature and faster mineralization under polyethylene mulching caused increased P uptake over other land configurations. The favorable hydro-thermal regime of soil and lower crop-weed competition under poly mulch has increased the P uptake. Hugar et al (2010) also reported that uptake of nutrients like N, P and K by the crop was better due to poly ethylene mulching and most effective when mulched with thicker PE film.

Integrated nutrient management practices also significantly influenced the P uptake at flowering of *Bt* cotton (Fig. 4). Application of 100% RDF + Pressmud equivalent to 25 % RDN (S_5) had recorded higher phosphorous uptake (16.3 sand 26.8 kg ha^{-1}) over (S_2) application of 100 % RDF but was on par with (S_4) 100% RDF + FYM equivalent to 25 % RDN and 125% RDF followed by (S_1) Farmers practice . Increased P uptake in S_5 treatment was due to the direct addition of the P through pressmud and greater multiplication of soil microbes, which could convert organically bound P to inorganic form. The organic materials form a cover on sesquioxides and thus, reduce the phosphate fixing capacity of the soil. These results are in accordance with Raut et al (2008).

The interaction effect on phosphorous uptake at flowering and harvest was significant due to moisture conservation and integrated nutrient management practices. The treatment combination (M_4S_5 and M_4S_4) involving poly mulch on broad bed and application of 100% RDF along with either pressmud or FYM equivalent to 25% RDN had recorded higher mean P uptake at flowering (17.6 and 17.6 kg ha^{-1}) and at harvest (30.8 and 30.4 kg ha^{-1}), respectively. Thus, indicating that poly mulch on broad bed was comparatively more effective when RDF applied either with pressmud or FYM or application of 125% RDF alone. Higher drymatter production coupled with higher phosphorous content that reflected in higher P uptake at both stages of *Bt* cotton.

Potassium (K) uptake (kg ha^{-1}): Potassium (K) uptake among moisture conservation treatments exerted significant influence at flowering and at harvest (Fig. 5). Poly mulch on broad bed method recorded significantly higher K uptake (64.8 and 152.8 kgha^{-1}) during both the years compared to flat bed (55.3 and 116.4 kg ha^{-1}) and broad bed and furrow methods (58.3 and 127.6 kgha^{-1}) but it was comparable with ridge and furrow at flowering and significantly superior at harvest (64.8 and 138.2 kg ha^{-1}). This significant response could be due to the significant dry matter production among the treatments at different crop growth stages. The favorable hydro-thermal regime of soil, higher temperature, faster mineralization and lower crop weed competition under poly mulch had increased the K uptake by plants. At flowering, ridge and furrow, which in turn was comparable with broad bed and furrow method during both the years of experimentation, whereas, ridge and furrow treatment was significantly superior over BBF at harvest. Broad bed sand furrow and flat bed methods were on par with each other. This was due to the optimum availability of moisture that led to higher uptake of K for proper growth and development of plants, resulted in higher K uptake as compared to flat bed method. The major portion of potassium moves to the roots by diffusion process though water films around the soil particles. In flat bed, under moisture stress condition the films become thinner and path length of ion movement increases. Hence, movement of potassium to the roots reduced.

Application of inorganics along with organics and graded level of fertilizers had exerted significant influence on potassium uptake at flowering (Fig. 5). Application of (S_5) 100% RDF + Pressmud equivalent to 25 % RDN treatment had recorded higher potassium uptake (61.6 and 144.0 kg ha^{-1}) over remaining integrated nutrient management practices. S_5 treatment was on par with (S_4) 100% RDF + FYM equivalent to 25 % RDN and application of (S_3) 125% and. (S_2) 100% RDF was followed by (S_1) Farmers practice. S_1 was in turn comparable with (S_2) 100 % RDF (57.1 and 117.3 kg ha^{-1}). Higher K uptake could be due to the significant

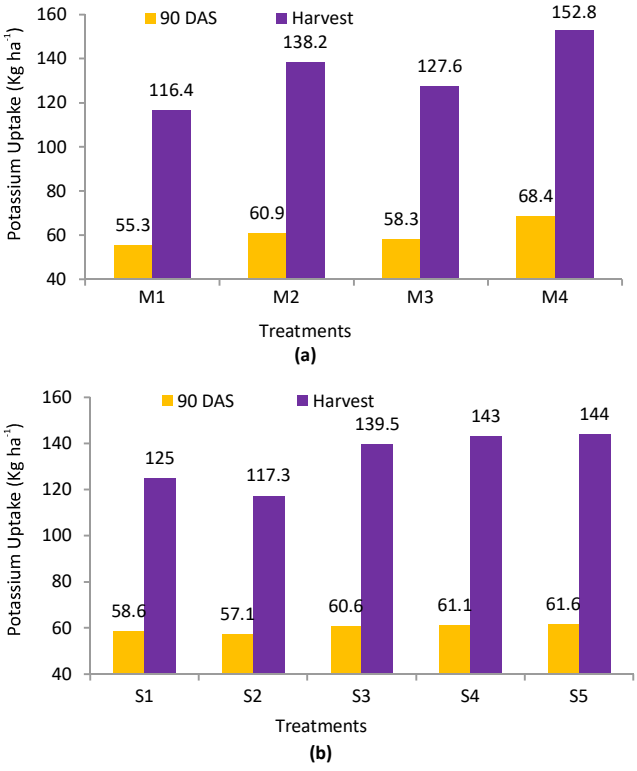

Fig. 5. Effect of (a)moisture conservation practices and (b) INM practices on potassium (K) uptake (kg ha^{-1}) by *Bt* cotton at flowering and at harvest

drymatter production among the treatments at flowering. Higher uptake of potassium under S_5 treatment was due to addition of potassium to available pool of the soil besides the reduction in potassium fixation and release of potassium.

Interaction between soil moisture conservation practices and integrated nutrient management practices were significant on K uptake during both the years of experimentation and in pooled results. Treatment combination M_4S_5 involving poly mulch on broad bed and application of RDF along with pressmud equivalent to 25% RDN recorded significantly highest mean K uptake at flowering and at harvest (66.6 and 166.0 kg ha^{-1}). This treatment was found on par with M_4S_4 poly mulch on broad bed and application of RDF along with FYM equivalent to 25% RDN and M_4S_3 application of 125% RDF. Thus, indicating that poly mulch on broad bed was more effective when RDF was applied either with pressmud or FYM or application of 125% RDF alone.

Physical, Physico-Chemical and Chemical Properties of Soil

Soil OC (%): The initial soil organic carbon content was 0.41 (%). There were no significant differences among the moisture conservation practices and nutrient management practices and due to their interaction during both the years of experimentation (Table 3). However, slight increase in OC was observed in 100% RDF + pressmud (0.42 %) or FYM equivalent to 25 % RDN (0.42 %) applied plots. The soil OC values varied between 0.40 to 0.42 % with relatively higher values in treatments consisting of organics (FYM and pressmud) over inorganics alone. Kumar et al (2017) also indicated the efficiency of pressmud based organics improve physical and chemical properties of soil.

Available N (kg ha^{-1}): The initial soil available nitrogen was 182 kg ha^{-1}. The post-harvest nitrogen status of the soil varied non significantly due to moisture conservation practices and significantly due to INM practices during both the years of study. However, their interaction effect was found to be non-significant (Table 3). The land configuration treatments had no significant effect on available nitrogen content of soil after harvest of the crop. However, the available nitrogen content varies between 179.7 and 186.1 kg ha^{-1} among different moisture conservation treatments. Integrated nutrient management practices also significantly influenced the available N after harvest of *Bt* cotton. Application of 125% RDF (194.3 kg ha^{-1}) recorded significantly higher available nitrogen as compared to rest of the treatments. This was on par with farmers practice and remaining treatments and significantly superior over 100 % RDF (160.7 kg ha^{-1}). The increase in available nitrogen under 125% RDF and also with organic manures was due to the direct supply of higher nitrogen as well as enhanced microbial activity which improved the nitrogen transformations like ammonification and nitrification. In farmers practice, application of higher dose of nitrogen (184 kg ha^{-1} and 3.75 t FYM ha^{-1}) lead to increase in available nitrogen. The results are in agreement with the findings of Satyanarayana Rao and Janawade (2009). Interaction between soil moisture conservation practices and integrated nutrient management practices were non-significant during with respect to pooled results.

Available P (kg ha^{-1}): The available phosphorous content of soil also increased with maturity of the crop. There was a buildup of available P_2O_5 over the initial value of 46.8 kg P_2O_5 ha^{-1}. The available P was significantly affected by moisture conservation practices and integrated nutrient management practices during both the years of experimentation. The interaction effect was also significant (Table 4). The initial soil test value indicated that it had soil available phosphorous of 46.8 kg ha^{-1}. The data indicated significant effect of moisture conservation treatments on soil available P. Poly mulch on broad bed method recorded significantly higher P availability (57.4 kg ha^{-1}) during both the years compared to all other

Table 3. Effect of moisture conservation practices and INM on OC (%)and available nitrogen(kg ha^{-1}) (Pooled data)

Treatments	OC (%)	Available nitrogen (kg ha^{-1})
Main treatments		
M_1 – Flat bed (Control)	0.41	179.7
M_2 – Ridge sand furrow	0.41	184.0
M_3 – Broad bed and furrow	0.41	182.1
M_4 – Poly mulch on broad bed	0.41	186.1
CD at 5%	NS	NS
Sub treatments		
S_1	0.41	193.0
S_2	0.41	160.7
S_3	0.40	194.3
S_4	0.42	182.2
S_5	0.43	184.7
CD at 5%	NS	14.6
CV	7.3	8.8
Interaction		
M XS		
CD at 5%	NS	NS
S X M		
CD at 5%	NS	NS

S_1 : Farmers practice, S_2 : 100% RDF, S_3 : 125% RDF, S_4 : 100% RDF + FYM equivalent to 25% RDN , S_5: 100% RDF + Pressmud equivalent to 25% RDN

moisture conservation. The less loss of phosphorus has aided in buildup of soil phosphorus up to harvest as compared initial status in poly mulch treatment. Poly mulch treatment was followed by ridge and furrow (54.0 kg ha^{-1}), which was on par with BBF and also recorded significantly higher available P as compared to flat bed method (51.2 kg ha^{-1}). Broad bed sand furrow method was in turn on par with flatbed method. Raised bed land configuration improves physico-chemical environment of soil through facilitating adequate air and water movement and ultimately improves nutrient availability. Similar results have also been earlier reported by Raising and Karthik (2022). Integrated nutrient management practices also significantly influenced the soil available P of *Bt* cotton. Significantly higher soil P (57.2 kg ha^{-1}) was in farmers practice (S_1) treatment. This was due to application of higher dose of P (101 kg P_2O_5) at later stages *i.e.* 20-25 DAS and 40-45 DAS of crop growth, which was not taken by the crop in farmers practice. This was on par with (S_3) application of 125% RDF (57.0 kg ha^{-1}). Increase in soil available phosphorus was due to direct addition of P from high dose of inorganic fertilizer. Next best treatment was (S_5) 100% RDF + Pressmud equivalent to 25 % RDN which was on par with 100% RDF + FYM equivalent to 25 % RDN (S_4) followed by (S_2) application of 100% RDF. Kalaivanan and Omar Hattab, (2008) reported improvement in soil physico-chemical properties with application of pressmud to soil. Interaction between soil moisture conservation practices and integrated nutrient management practices were found to be significant during both the years of experimentation and in pooled results. Treatment combination involving poly mulch on broad bed and farmers' practice (M_4S_1) recorded significantly highest mean soil available P (60.5 kg ha^{-1}). This treatment was on par with (M_4S_3) combination of poly mulch on broad bed and application of 125 % RDF. All *in-situ* moisture conservation treatments along with farmers practice recorded higher soil available P. Significantly lower soil available P was observed in the treatments applied with pressmud and FYM which was due to increased uptake of nutrients by the crop. These results revealed that the *Bt* cotton crop removed substantial amount of phosphorous towards growth and development to meet its requirement.

Available K (kg ha^{-1}): Available K content of the soil increased in all the treatments compared to the initial status during both the years of experimentation except (S_2) application of 100% RDF during 2015-16. Available K was not influenced by moisture conservation practices and significantly influenced by integrated nutrient management practices during both the years (Table 4). The initial soil test value indicated that it had soil available potassium of 432.0 kg ha^{-1}. The land configuration treatments had no significant effect on available potassium content of soil after harvest of the crop. Integrated nutrient management practices significantly influenced the available K of *Bt* cotton (Table 4). During both the years of experimentation, among different INM practices, (S_1) farmers practice (447.0 kg ha^{-1}), (S_3) application of 125% RDF (442.1 kg ha^{-1}) and (S_5) 100% RDF + Pressmud equivalent to 25 % RDN (438.6 kg ha^{-1}) were on par with each other and recorded significantly higher post-

Table 4. Effect of land configurations and nutrient management practices on available phosphorus(kg ha^{-1}) and available potassium (kg ha^{-1}) in the soil

Treatments	S_1	S_2	S_3	S_4	S_5	Mean
Available P (kg ha^{-1}) pooled						
M_1 - Flatbed (control)	54.5	45.3	58.2	47.7	50.2	51.2
M_2- Ridge sand furrow	57.8	51.0	55.4	52.3	53.5	54.0
M_3- BBF	56.0	49.1	55..3	50.6	51.0	52.4
M_4- Poly mulch on BBF	60.5	57.0	59.3	55.0	55.2	57.4
Mean	57.2	50.6	57.0	51.4	52.5	53.8
C.D at 5%		2.0	1.2	2.5	2.7	
Available K (kg ha^{-1})						
M_1 - Flatbed (control)	442.3	420.4	437.1	429.0	433.5	432.5
M_2- Ridge sand furrow	448.1	430.5	443.5	440.0	441.2	440.7
M_3- BBF	444.4	426.1	441.0	432.7	435.5	435.8
M_4- Poly mulch on BBF	453.0	435.2	446.6	442.4	444.2	444.3
Mean	447.0	428.0	442.1	435.9	438.6	438.3
C.D at 5%		NS	10.5	12.2	15.5	
CV		7.4				

harvest potassium values over application of (S_2) 100 % RDF (428 kg ha^{-1}). This could be due to more intense weathering, release of K from pressmud, application of K fertilizers and upward translocation of potassium from lower depth along with capillary raise of groundwater. (S_5) Application of 100% RDF + Pressmud equivalent to 25 % RDN was on par with (S_4) application of 100% RDF + FYM equivalent to 25% RDN (435.9 kg ha^{-1}). These findings are in agreement with those of Yadav et al (2019) and Umesh et al (2018). Interaction between soil moisture conservation practices and integrated nutrient management practices were found to be significant during both the years of experimentation and in pooled results. Treatment combination involving poly mulch on broad bed and farmers' practice (M_4S_1) recorded significantly highest mean available K (453 kg ha^{-1}).This treatment was on par with combination of ridge sand furrow configuration with farmers' practice of nutrient application (M_2S_1). All *in-situ* moisture conservation treatments along with farmers practice recorded higher soil available K followed by all *in-situ* moisture conservation treatments along with 125 % RDF. With increased application of K level, the soil available K also increased. Significantly lower available potassium was observed in the treatments applied with pressmud or FYM which was due to increased uptake of nutrients by the crop.

CONCLUSION

BBF laid with poly mulch in addition to application of 100% RDF + 25% RDN through organics (pressmud or FYM) was comparable to BBF laid with poly mulch and application of 125% RDF through inorganics in terms of yield attributes (bolls per plant and boll weight) and seed cotton yield, root weight and volume, NPK uptake by plant, and available organic carbon (%) and available soil NPK status, among the land configuration treatments. Application of 100% RDF + 25 % RDN through Pressmud has recorded highest yield and yield attributes, root weight and volume, NPK uptake and available NPK status in the soil which was at par with 100% RDF + FYM equivalent to 25 % RDN and 125% RDF alone among the nutrient management practices. Based on the results, poly mulch on broad bed in combination with either pressmud or FYM or application of 125% RDF alone can be well recommended to farmers of Telangana. Therefore, it can be concluded that poly mulch on broad bed was comparatively more effective when RDF applied along with either pressmud or FYM or application of 125% RDF alone can be well recommended to farmers of Telangana.

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Studies on Sandalwood Tree (*Santalum album* L.) Based Agroforestry System in Haveri District of Karnataka, India

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***Abstract*:** Study was conducted during the year 2018-2021 at College of Forestry, Sirsi for studied on sandalwood tree (*Santalum album. L.*) based Agroforestry systems in Karnataka. The important objectives of this study were screening of secondary host plants on heartwood, oil content and carbon sequestration potential of sandalwood tree in different agroforestry systems of Karnataka in Haveri district and revealed that 47.32 per cent in clear bole height of sandalwood trees with *Swietenia mahogany* and 42.43 per cent with *Calliandra haematocephala* as compared to other secondary hosts. The volume of the main stem of sandalwood was increased by 85.08 per cent with *Moringa oleifera* and 83.37 per cent with *Casuarina equisetifolia* as secondary host for sandalwood trees. The heartwood content of sandalwood tree increased by 68.75 per cent with *Casuarina equisetifolia* and 64.36 per cent in *Sesbania grandiflora.* The per cent oil content of sandalwood tree was increased by 95.20 per cent with *Casuarina equisetifolia* and 92.75 per cent with *Swietenia mahogani* as secondary host of sandalwood tree. Carrbon sequestration potential of different host based sandalwood planation was highest capacity with the host of *Murraya koenigii* (21.05 tha^{1}) and *Moringa oliefera* (20.19 tha^{1}).

Keywords: Sandalwood, Heartwood and path coefficient analysis

Indian sandalwood tree (*Santalum album* L.) one of the world's most valuable commercial timbers and is currently valued globally for its heartwood and oil. According to the predictions of Thomson(2020) the local demand for sandalwood oil in India will rise to a minimum of 250 tons in 2040. Wild sandalwood might yield ~100 tons of oil in 2040 and based on recent data Sandalwood plantations were taken up in a massive scale at around 2019 (~30000 ha) in India. High economic worth of Indian sandalwood is due to its heartwood and oil content. Heartwood is defined as inner rings of xylem deposited with metabolic byproducts that is hard and nonliving, which is usually dark in color. Initiation and heartwood formation in Indian sandalwood usually begins from the age of 6-7 years and the best quality heartwood is observed at the age of 30 years whose girth may be around 50 to 60 cm. Karnataka once was famous for sandalwood trees in the world. Sandal trees are necessarily grown with other plants, preferably leguminous plants for providing nutrients and water for Sandal trees (Rocha et al 2017). The semi-parasitic nature of the tree, its adaptability to grow in semiarid tracts and its potential to grow in combination with horticultural species as secondary hosts make it a potent agroforestry species.

Carbon conservation and carbon sequestration require the support of socio-economic improvements in numerous developing nations. Tree crop plantations offer the potential to combine climate change mitigation with economic growth, as they can sequester carbon while providing wood and non-wood products to meet domestic and global market demands. Financial compensation for such plantations may be eligible under the Clean Development Mechanism of the United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol. It has also been proposed for inclusion in REDD+ (reducing emissions from deforestation, forest degradation, and enhancement of forest carbon stocks), which is under negotiation within the United Nations FCCC (Kongsager et al 2013). The carbon sequestration potential (CSP) of agroforestry has been estimated in numerous studies. Globally, carbon accumulation in agroforestry ranges from 0.29 to 15.2 Mg C ha^{1} $year^{1}$ aboveground and 30 to 300 Mg C ha^{1} $year^{1}$ for soils down to 1 m depth (Albrecht and Kandji 2003). However, carbon stocks in agroforestry vary based on geographical location and climatic zone (Basu 2014). In India, the biomass, carbon stock, and carbon sequestration potential of different agroforestry systems also vary across regions (Rai et al 2009, Kumar 2010, Koul and Panwar, 2012, Devagiri et al 2013). These differences in carbon density and carbon sequestration potential among AFS are primarily attributed to climatic conditions and other site-specific factors due to India's diverse geography and climate. Furthermore, variations in methodological approaches, such as biomass

assessments based on standing tree volume, destructive sampling, allometry, and spectral modeling using remote-sensing data, can lead to differences in estimated biomass carbon values. Quantifying carbon stocks associated with tree growth at different spatial and temporal scales is a complex task, influenced by factors like planting geometry on farmlands, soil conditions, local climate, tree management practices, and genetic parameters. For instance, trees growing in natural or wild conditions tend to have greater height, larger trunk diameter, and stronger physical and mechanical properties than trees growing in an agricultural landscape (Kozakiewicz et al 2021, McKinney and Kozakiewicz 2021). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, there is limited information available regarding the biomass, carbon stock, and sequestration potential of both natural forests and trees outside forests at the national and regional levels. Present study effort was made to estimate the total biomass and carbon sequestration potential of different age and different agro climatic zones of Karnataka state Sandalwood plantations.

MATERIAL AND METHODS

The comprehensive survey was conducted across various locations within the Haveri district, gathering essential data through meticulously designed questionnaires. Within each location, an unbiased selection process was implemented, randomly choosing five trees for a detailed assessment of their heartwood and oil content. The study recorded vital observations, including the location's name, the age of each tree in years, the introduction of secondary host species (Table 1, 2), method of planting, adopted spacing (measured in meters), various growth parameters, the percentage of heartwood formation, and the percentage of oil content in each tree. Furthermore, the study area and survey encompassed an assessment of site characteristics such as location coordinates (latitude and longitude), altitude in meters, rainfall measurements in millimeters, temperature data, soil types and management practices (Table 3). For calculation of canopy volume the study area was comprised 4 locations of Northern Transitional agroclimatic zone of Karnataka. The estimation of canopy volume was conducted using a specific formula, as outlined by Thorne et al (2002). This comprehensive survey aims to provide valuable insights into the cultivation and characteristics of trees in the Northern Transition zone.

$$V = \frac{2}{3}\pi h \left(\frac{a}{2} \times \frac{b}{2}\right)$$

Where, h is the height of the canopy; a and b are spread of mid canopy at perpendicular axes.

Volume of the main stem: The main stem volume indicates the dry matter accumulation in the sandalwood tree and marketable yield. It was calculated considering the main stem as cylinder using the formula as a non-destructive observation. V = πr2h, where h is clear bole height and r is radius derived from tree girth.

Table 2. Predominant secondary hosts identified and sample size

Secondary host plants	Common name	Age (Yrs)	Sample size
Melia dubia	Hebbevu	8.5	5
Sesbania grandiflora	Agase	5.5	4
Tectona grandis	Teak	9	3
Mangifera indica	Mango	8.5	6
Swietenia mahogani	Mahogany	8.0	3
Emblica officinalis	Amla	8.5	3
Punica granatum	Pomegranate	9.0	4
Murraya koenigii	Curry leaf	6.5	3
Manilkara zapota	Sapota	7.0	4
Moringa oleifera	Drumstick	5.5	3
Pongamia pinnata	Karanj	7.5	3
Casuarina equisetifolia	Beef wood	8.0	2
Dalbergia latifolia	Rose wood	7.5	2
Calliandra haematocephala	Calliandra	6.5	3

Table 1. Location and annual rainfall of study area

Location	Latitude (North)	Longitude (East)	Elevation (m)	Mean annual rainfall (mm)	Mean annual temperature (°C)	
					Maximum	Minimum
Kudapalli	14.46	75.56	571.36	753	34.50	26.50
Hirekerur	14.45	75.39	608.15	718	34.00	26.20
Nandihalli	14.50	75.63	541.19	695	33.80	26.90
Byadagi	14.67	75.48	601.33	710	33.50	26.50
Hiremaranahalli	14.92	75.48	531.30	735	34.10	27.15
Savanur	14.97	75.33	592.98	724	33.00	26.50

Estimation of heart wood formation and oil content in *Santalum album* wood: Data were collected from three replicates/sample trees within each girth class, with recorded measurements including girth at breast height (GBH) and tree height. To extract core samples from each tree, a Haglof increment borer was employed, encompassing the bark, sapwood, transition region, and heartwood portions. The heartwood section of the core sample was used for oil content estimation, and these core samples were collected at breast height level, wrapped in blotting paper, and placed in desiccators. From these core samples, parameters such as bark thickness, sapwood radius, transition region, and heartwood radius were estimated by converting tree girth to tree diameter, facilitating the calculation of heartwood percentage. Sandalwood oil content was assessed using the method developed by non-destructive and convenient approach for quickly screening oil content in standing trees. Subsequently, the heartwood portion was finely sliced using a blade. A sample weighing 100 mg was measured on a precision balance, followed by the addition of 100 ml of hexane (boiling point range of 60-70°C) in a 100 ml standard flask. These samples were left undisturbed for 18 hours with periodic agitation. The resulting supernatant was collected in a quartz cell, and its optical density was measured at 219 nm (maximum) using a UV Spectrophotometer (Shimadzu-240). The statistical significance was determined using a student t-test in Microsoft Excel 2010 at a 95 percent probability level.

RESULTS AND DISCUSSION

Influence of host trees on growth, heart wood initiation and oil content on nine year old sandalwood trees at Haveri district: Sandal wood clear bole height under different hosts showed significant difference. The significantly higher clear bole height was with *Swietenia mahogani* (2.24 m) followed by *Calliandra haematocephala* and *Dalbergia latifolia.* The lowest sandal wood clear bole height was with *Emblica officinalis* (1.18 m) which is on par with the host of *Melia dubia.* Among 14 secondary hosts for sandalwood tree significantly higher tree girth was with *Mangifera indica* (32.63 cm) which was on par with the other host *C. equisetifolia*, *S.grandiflora*, *P/ pinnata* followed by *E. officinalis*, *D. latifolia* and *Melia dubia*. The lowest tree girth was noticed in *Manilkara zapota* (13.17 cm) which was on par with host *T. grandis*, *S.mahogany, M. koenigii* and *C.haematocephala*. The significantly higher volume of main stem was with *M. indica* (12.27 dm^3) which was on par with T.*grandiflora*, *C.equisetifolia*, *P. pinnata*. The lowest volume of main stem was in higher heart wood content was with *C. equisetifolia* (25.93 %) followed by *S.grandiflora*, *M. dubia*, *M. indica*, *M zapota*. The lowest heart wood content was with *Punica granatum* (8.17 %) which was on par with *Moringa oleifera*, *Tectona grandis* and *Dalbergia latifolia*. The significantly higher oil content was with *Casuarina equisetifolia* (3.13 %) followed by *Swietenia mahogany* and *Manilkara zapota.* The least was with *Tectona grandis* (0.15 %) (Table 4, Fig. 1). Jain et al (2003) reported that the essential oil in *Santalum album* tree varies one to eight per cent depending on the age, soil, climate and genetic factors. Similarly, Mishra et al (2018) reported that sandalwood trees aged between 8 to 35 years and having the girth class between 30 to 80 cm recorded oil content in the range between 1.0 to 4.0 per cent and with increase in age. Sandeep et al (2016) observed that in Maharashtra, Orissa, Punjab, Rajasthan reported that maximum oil concentration is 1.0 to 2.29 per cent and estimated heartwood content was significantly varied with girth class and locations and heartwood content and oil per cent varied significantly with girth class, locations and host. The heartwood formation is not uniform with respect to the different host plants (Liu et al 2011) and also it depends on genetic makeup of the tree (Arunkumar et al 2012) and girth (Brand et al 2012, Sandeep et al 2016)

Influence of host trees on carbon and biomass accumulation in nine years old Sandalwood plantations at Haveri district: Different host trees in Haveri significantly influenced the biomass and carbon storage in Sandalwood trees (Table 5). Maximum total tree height was *D. latifolia* (2.76 m) on par with *M. koenigii*. Minimum sandalwood height

Table 3. Soil type, spacing and management practices followed in sandalwood trees and host plants

Location	Soil type	Spacing adopted (m)		Management practices followed
		Sandal	Sandal to host	
Kudapalli	Black soil	2x2	1x1	Pruning, drip irrigation, soil working
Hirekerur	Red clay	4x4	2x2	Pruning, soil working and weeding
Nandihalli	Loamy soil	3x3	1x5	Pruning, weeding, soil working
Byadagi	Laterile soil	5x4	2x2	Pruning, irrigation
Hiremaranahalli	Red loamy	3x3	2x2	Pruning, weeding
Savanur	Black soil	3x2	1x1	Pruning, drip irrigation, soil working

was with *S. mahogani* (1.92 m). Volume of sandalwood tree was significantly higher with *C. equisetifolia* (18.31 dm^3) which was on par with *M. indica.* Total AGB was significantly maximum with *M.koenigii* (35.55 t ha^{-1}) whereas, minimum of 7.05 t ha^{-1} with *M. dubia.* In the same fashion BGB and CS were maximum with *M. koenigii* (BGB- 9.24 $tha^{-1}$and CS- 21.05 tha^{-1}) and minimum with *M. dubia* (BGB- 1.83 $tha^{-1}$and CS- 4.17 t ha^{-1}) canopy volume was maximum with *S. grandiflora* (2.11 m^3) which was on par with *M. koenigii*, *E. officinalis and M. dubia and* minimum was in *T. grandis.* In a

Table 4. Influence of host trees on growth, heart wood initiation and oil content on nine year old sandalwood trees at Haveri district

Secondary host plants	Sandal clear bole height (m)	Tree girth (cm)	Volume of main stem (dm^3)	Heart wood content (%)	Oil content (%)
Melia dubia	1.37	19.17	4.00	17.17	1.80
Sesbania grandiflora	1.47	29.55	10.91	22.93	1.54
Tectona grandis	1.33	13.25	1.76	9.50	0.15
Casuarina equisetifolia	1.58	30.50	11.01	25.93	3.13
Swietenia mahogani	2.24	15.17	1.83	13.67	2.07
Emblica officinalis	1.18	21.00	4.15	11.83	1.22
Punica granatum	1.31	18.12	3.78	8.17	0.92
Murraya koenigii	1.40	16.58	3.05	13.83	1.32
Manilkara zapota	1.23	13.17	1.67	16.67	1.95
Moringa oleifera	1.20	18.25	3.27	10.50	0.77
Pongamia pinnata	1.43	28.44	9.02	13.20	1.03
Mangifera indica	1.40	32.63	12.27	17.02	1.73
Dalbergia latifolia	1.94	20.71	4.54	9.30	0.91
Calliandra haematocephala	2.05	16.87	4.76	13.50	1.28
Mean	1.51	20.96	5.43	14.52	1.42
CD (p=0.05)	0.62	4.33	3.97	2.49	0.41

Table 5. Influence of host trees on carbon and biomass accumulation in nine years old Sandalwood trees at Haveri district

Secondary host plants	Total tree height (m)	Volume of sandal tree (d m^3)	Total *AGB of sandal (t ha^{-1})	Total *BGB of sandal (t ha^{-1})	Total carbon sequestered in sandal (t ha^{-1})	Canopy volume (m^3)
Melia dubia	2.27	14.53	7.05	1.83	4.17	1.45
Sesbania grandiflora	2.03	16.47	13.31	3.46	7.88	2.11
Tectona grandis	2.05	13.82	14.90	3.87	8.82	0.66
Mangifera indica	2.30	17.50	10.61	2.75	6.28	1.07
Swietenia mahogani	1.92	13.85	14.93	3.88	8.84	0.99
Emblica officinalis	2.15	14.72	8.93	2.32	5.28	1.58
Punica granatum	2.22	14.16	8.59	2.23	5.08	1.15
Murraya koenigii	2.51	14.66	35.55	9.24	21.05	1.76
Manilkara zapota	2.23	13.68	14.75	3.83	8.73	0.84
Moringa oliefera	2.15	14.06	34.11	8.86	20.19	1.26
Pongamia pinnata	2.15	16.35	13.22	3.43	7.82	0.99
Casuarina equisetifolia	2.30	18.31	19.74	5.13	11.69	1.32
Dalbergia latifolia	2.76	15.73	9.54	2.44	5.57	1.17
Calliandra haematocephala	2.22	15.50	25.07	6.51	14.84	1.38
Mean	2.23	15.24	16.45	4.27	9.73	1.27
CD (p=0.05)	0.38	0.87	1.11	0.29	0.66	0.70

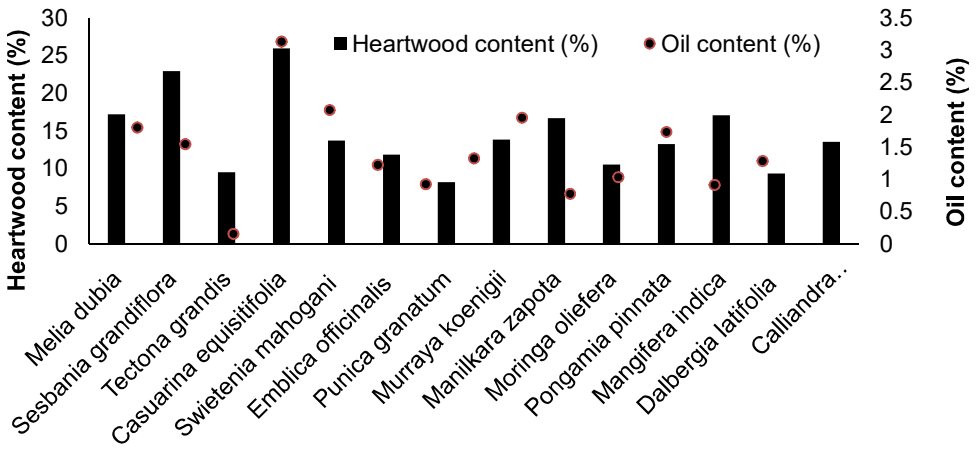

Fig. 1. Influence of host trees on heartwood and oil content on nine year old sandalwood trees at Haveri district

specific area within the northern transition zone of Haveri District, the total aboveground biomass (AGB) exhibited significant variation, with *M. koenigii* showing the highest value at 35.55 t ha-1, while the lowest value of 7.05 t ha^{-1} was for *M. dubia*. Similarly, the belowground biomass (BGB) and carbon sequestration (CS) also followed this trend, with *M. koenigii* having the maximum values (BGB- 9.24 t ha^{-1} and CS- 21.054 t ha^{-1}), and *M. dubia* having the minimum values (BGB- 1.83 t ha^{-1} and CS- 4.18 t ha^{-1}, respectively). This variation could be attributed to the favorable soil and climatic conditions in the region. Chavan (2009) focused on biomass accumulation and carbon sequestration in tree species planted under shelterbelts in the northern transitional zone of Karnataka and observed that *Acacia auriculiformis* had the highest biomass accumulation, followed by *A. indica* . Swamy et al (2017) also emphasized the potential of sandalwood tree-based systems for carbon sequestration in the northern transitional zone of Karnataka, highlighting it as one of the promising options for storing carbon both in plants and in the soil.

CONCLUSIONS

With effective pruning, drip irrigation, soil working management of Sandalwood plantation followed with significant host related heartwood formation and oil content in Haveri district of Karnataka. Haveri district of belongs to hilly zone tends to *Casuarina equisetifolia, Sesbania grandiflora* and Mangifera indica hosts performs to allow sandalwood with higher heartwood and oil content. Carrbon sequestration potential of different host based sandalwood planation was highest capacity with the host of *Murraya koenigii* and *Moringa oliefera*. A comprehensive exploration of host tree species across various agroclimatic zones in Karnataka is imperative. The refinement of core wood sample collection methods, incorporating advanced techniques such as Electrical Resistivity Tomography (ERT), can significantly enhance our ability to estimate heartwood, sapwood, and detect stress and decay in trees. A systematic evaluation of suitable host trees for sandalwood cultivation is of utmost importance. It is essential to gain a deep understanding of the intricate relationship between heartwood formation, age gradation, and the consistency of host trees across different locations. A thorough investigation into the physiological responses of secondary host plants under field conditions is a crucial aspect of this research. Moreover, conducting economic analyses of sandalwood-centered agroforestry systems across diverse agroclimatic zones in Karnataka is vital for informed decision-making and sustainable.

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Aquatic Weeds and Rice Chaff: Potential Inputs for Generation of Organic Manures in Rice Based Integrated Farming System

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Abstract: An experiment was carried out at Integrated Farming System Research Station (IFSRS), Kerala Agricultural University, India to assess the potential of aquatic weeds and rice chaff associated with rice-based IFS in generating good quality organic manures. In the study, different substrates like water hyacinth, salvinia, wild taro and rice chaff were co-composted using organic inputs *viz.,* cow dung, goat manure or poultry manure in the ratio 4:1:1 on volume basis. Parameters like time taken for composting, per cent recovery, pH, EC, C: N ratio and nutrient content of mature composts were analyzed. Co-composting of wild taro with cow dung and goat manure in the ratio 4:1:1 (v/v) resulted in significant earliness in maturity and narrower C: N ratio, comparable to water hyacinth + cow dung + goat manure. Percentage recovery was significantly higher in the co-composting treatment of rice chaff with cow dung and poultry manure. Regarding the macro nutrient content, co-composting of water hyacinth with cow dung and goat manure recorded significantly higher NPK content. The study therefore highlights the potential of bio resources in a rice-based IFS to generate good quality organic manures.

Keywords: Aquatic weeds, Co-composting, Rice chaff, Bio recycling, Rice-based IFS

The switchover to integrated farming systems from the traditional monoculture was felt during the context of Covid-19 pandemic in India. The fundamental principle of IFS; bio recycling gives thrust in reducing the purchase of external inputs and maximum utilization of bio resources within the system. The main concept of integrated farming systems is that the byproduct of one enterprise becomes the input for another. Efficient utilization of all possible organic resources generated in IFS therefore requires prime consideration (Sharma et al 2019). In this way, over dependence on chemical fertilizers can be reduced and eco-friendly farming is encouraged in an IFS. Ecofriendly farming techniques have multiple benefits especially on long term maintenance of soil health (Bhatia et al 2016).

Rice, is the main food crop of India and it has a great role in shaping the lives of people. Rice based integrated farming systems offer great scope for bio recycling and on farm generation of inputs (Sudha et al 2020). Aquatic weeds associated with rice growing wetlands and adjacent water bodies generate huge amount of biomass and contain plant nutrients, making them ideal substrates for composting (Dissanayaksa et al 2023). Rice chaff, a crop residue obtained during winnowing of paddy is yet another resource which could be effectively recycled (Thiyageshwari et al 2018). Besides, nitrogen rich manures from livestock also could be utilized for recycling. Aquatic weeds are often considered a menace due to their fast spread as well as negative impact on aquatic environment. Wild taro (*Colocasia esculenta*) is an aggressive weed that can form dense stands along waterways (Cozad et al 2018). Vast areas of lowland paddy in Kerala are badly infested with aquatic weeds *Eichhornia crassipes* and *Salvinia molesta,* hindering paddy cultivation and the losses caused by these weeds range from 30 to 60 per cent (Jayan and Sathyanathan 2012). Utilizing the biomass of these weeds for manure production offers dual benefits of weed control and nutrient generation. Rice chaff, obtained during winnowing of paddy is another abundantly available bio resource in a rice-based IFS. Rice chaff often considered as a waste product is a rich source of silica (Sekifuji and Tateda 2019) and the prospects of recycling rice chaff in such an angle is less studied in Kerala. The potential of aquatic weeds and rice chaff in bio recycling is immense. But there are certain factors that challenge the possibility of recycling these substrates. Rice chaff has a wide C: N ratio (Demir and Gulser 2015) as well as high cellulose and lignin contents (Singh 2018) hindering microbial degradation. Similarly, the aquatic weeds also have wide C: N ratio and ligno-cellulose content. Composting these substrates with nitrogen rich manures can only tackle this problem.

Composting is an effective method to sustainably recycle agro-wastes, weeds *etc*. into useful products and is an

effective solid waste management technique for preparing nutrient rich manure from crop residues having wider C: N ratio (Waqas et al 2023). The use of co-composting technology is preferred for recycling many agricultural wastes into safer and more stable materials as soil amendment (Omar et al 2021). The prospects and possibilities of co-composting of organic resources in a rice based integrated farming system have been already proved in Kerala (Athira et al 2021). Many studies are oriented towards co-composting of water hyacinth and salvinia, but less studies are reported regarding the co-composting of rice chaff and wild taro. As reported by Singh et al (2015), composting of salvinia biomass with adequate quantity of cattle manure resulted in good quality compost. Addition of cattle manure and rice husk hastened the composting process of *Salvinia natans* (Singh 2015). Therefore, the present study aimed to generate good quality composts from the bio resources *viz.,* water hyacinth, salvinia, wild taro and rice chaff via co-composting with organic manures such as cow dung/ poultry manure or cow dung/goat manure in 4:1:1 ratio (v/v). The composts thus generated can substitute a part of chemical fertilizers thereby promoting ecofriendly farming.

MATERIAL AND METHODS

The experiment was carried out during September to December 2021 at the Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala under Kerala Agricultural University (KAU) located at 8° 28' 28" North latitude and 76° 57' 47" East longitude, at an altitude of 5 m above MSL. The composting study was laid out in completely randomized design with eight treatments and three replications. Different aquatic weeds were collected from the channels and bunds of IFSRS, Karamana and were given a wilting period of 10 days. Partially withered rice chaff obtained after 10 days of harvest from the variety Uma was also utilized for composting. Later these substrates were mixed with either cow dung/poultry manure or cow dung/goat manure in the ratio 4:1:1 on volume basis and filled in concrete pits of size 1 m^3 as per the treatments (Table 2). The nutrient content of manures and composition of different substrates used in the study are detailed in Table 1 and 3. The compost pits were turned once in a week to ensure aeration and easy decomposition. Adequate moisture levels were also maintained. Mature composts were sieved, shade dried and stored.

Observations such as time taken for maturity, per cent recovery (Table 4), chemical properties *viz.,* pH, EC and C: N ratio (Table 5) as well as nutrient content of mature composts (Table 6) were recorded by following standard procedures. Maturity of composts was determined initially based on visual observation and then confirmed upon C: N ratio narrowed down to less than 20 (Khater 2015). Per cent recovery was estimated by dividing the quantity of output to the quantity of input multiplied by 100. Samples obtained from each treatment on maturity were mixed with water in the ratio 1:5 and pH were measured using pH meter with glass electrode (Jackson, 1973). Compost-water solution used for determination of pH was again used for estimating electrical conductivity (EC) using conductivity meter (Jackson 1973). The carbon content of compost samples was determined using weight loss on ignition method (FAI 2017) and total N content was estimated by microkjeldhal method (Jackson 1973). The ratio of carbon to nitrogen was worked out and expressed as C: N ratio. For the estimation of P, nitric perchloric acid digestion (9:4) was followed by estimation with vanadomolybdate phosphoric yellow colour method

Table 1. Nutrient content of manures used in the study

Manure	N (%)	P (%)	K (%)
Cow dung	1.12	0.76	0.80
Poultry manure	1.79	0.75	0.98
Goat manure	2.30	0.81	1.24

Table 2. Co-composting of substrates using organic manures

T_1	Rice chaff + cow dung + poultry manure
T_2	Water hyacinth + cow dung + poultry manure
T_3	Salvinia + cow dung + poultry manure
T_4	Wild taro + cow dung + poultry manure
T_5	Rice chaff + cow dung + goat manure
T_6	Water hyacinth + cow dung + goat manure
T_7	Salvinia + cow dung + goat manure
T_8	Wild taro + cow dung + goat manure

Organic resources were mixed with manures in the ratio 4:1:1 (v/v basis)

Table 3. Composition of substrates before composting

Substrate	Lignin (%)	Cellulose (%)	C:N Ratio	N (%)	P (%)	K (%)
Rice chaff	20.28	41.12	61.34	0.90	0.49	0.97
Water hyacinth	18.60	29.35	39.30	1.07	0.67	1.18
Salvinia	17.71	35.15	58.54	0.73	0.61	0.47
Wild taro	15.25	23.76	39.12	0.63	0.25	0.38

using spectrophotometry (Jackson, 1973). K was estimated using nitric perchloric acid digestion (9:4) and flame photometry (Jackson 1973).

RESULTS AND DISCUSSION

Time taken for maturity: Different treatments had a significant influence on the time taken for maturity of composts. Co-composting of wild taro with cow dung and goat manure in the ratio 4:1:1 on volume basis recorded significant earliness in compost maturity, comparable to co-composting of water hyacinth with cow dung and goat manure. Significantly the longer time was observed in co-composting of rice chaff with cow dung and poultry manure in the ratio 4:1:1. Time taken for compost maturation was related to the initial composition of substrates *viz.,* lignin, cellulose contents and C: N ratio. The C: N ratio of different substrates used in this study followed the order; wild taro < water hyacinth < salvinia < rice chaff. As the C: N ratio of the composting substrate increases, the time taken by microbes to degrade those materials increases thereby prolonging the composting process (Yang et al 2021). The content of lignin and cellulose as well as C: N ratio was lower for the substrate wild taro; attributing to its early maturation. Factors such as wider C: N ratio, higher lignin and cellulose content of rice chaff could be related to the delay in compost maturation. Maruf et al (2017) opined that lignin and cellulose contents are high in rice chaff. High content of lignin in rice chaff hindered its decomposition by micro-organisms which in turn delayed the composting (Matin and Hadiyanto 2018). Thiyageshwari et al (2018) reported that the silica coating of rice chaff could also slow down composting process.

Recovery of compost: Recovery percentage indicates the quantity of output (compost) obtained per quantity of input (substrate) used for composting. T_1 (co-composting of rice chaff with cow dung and poultry manure in the ratio 4:1:1) recorded the highest recovery percentage (29.85 %) whereas the lowest recovery percentage (14.91 %) was recorded by T_8 (wild taro + cow dung + goat manure in 4:1:1 ratio). As compared to other substrates like salvinia, water hyacinth and wild taro, the moisture content was lower (16.91 %) and content of dry matter was higher in rice chaff which could be attributed to the higher recovery. Sreesvarna et al (2019) reported similar results of lower moisture content in rice chaff (8.64 %) which could result in higher recovery. Among the treatments, wild taro compost recorded significantly lower recovery. This could be related to the higher initial moisture content of wild taro (96.14 %) which added lesser biomass to the composting lot resulting in lesser recovery. Apart from this, the underground tubers of wild taro resist microbial degradation thereby reducing the recovery percentage. Wild taro has high moisture content (92.4 %) (Preiato, 2020) which reduces biomass addition to composting lot. In a composting trial conducted at United States using wild taro, Sembera et al (2019) reported that some of the propagules of wild taro remained undecomposed after composting and the propagules could be decomposed after an additional composting cycle only.

Table 4. Effect of different treatments on time taken for composting and percentage recovery

Treatments	Time taken (Days)	Recovery (%)
T_1	112.00	29.85
T_2	75.67	23.75
T_3	99.00	25.14
T_4	74.67	15.65
T_5	102.67	27.54
T_6	65.67	20.70
T_7	90.67	21.52
T_8	64.00	14.91
CD (p=0.05)	1.217	0.708

Table 5. Effect of different treatments on chemical properties of mature composts

Treatments	pH	EC (dS m^{-1})	C:N ratio
T_1	6.96	0.81	15.79
T_2	7.12	0.80	14.22
T_3	7.12	0.82	15.42
T_4	7.36	0.78	14.17
T_5	7.03	0.79	13.81
T_6	7.15	0.80	12.58
T_7	7.21	0.81	13.80
T_8	7.45	0.78	12.33
CD (p=0.05)	NS	NS	0.706

Table 6. Nutrient content of composts generated under different treatments

Treatments	N (%)	P (%)	K (%)
T_1	1.93	0.79	1.70
T_2	2.18	0.97	1.90
T_3	2.02	0.83	1.56
T_4	1.76	0.62	1.44
T_5	2.04	0.87	2.62
T_6	2.28	1.09	2.70
T_7	2.11	0.96	1.90
T_8	2.04	0.83	1.55
CD (p=0.05)	0.100	0.041	0.102

In the present study, among the different organic manures used for co-composting these substrates, poultry manure had an advantage over goat manure in terms of recovery percentage. Being low in moisture content, poultry manure added more of dry matter to the composting lot, naturally contributing to higher recovery. Guerra-Rodriguez et al (2000) had established the advantage of poultry manure in complete decomposition of composting material thereby avoiding wastage and hence better recovery. Yadav (2005) reported that, poultry manure added to the composting material in higher quantities could enhance the recovery of compost.

Major chemical properties of mature composts: The chemical properties *viz.,* pH and EC were not significantly influenced by different treatments. However, the C: N ratio differed significantly and the final C: N ratio had a connection with the type of substrate as well as organic manure combination used in the study. pH ranges from values 1 to 14. At the initial stages of composting, organic acids are produced which makes the pH acidic. Later on, the organic acids get neutralized and at the end of composting, the pH falls between 6 to 8. Different co-composting methods have no significant influence on the pH of composts. The pH of the composts generated in the study fell in the range of near neutral to slightly alkaline pH ranging from 6.96 to 7.45. Electrical conductivity varies depending on the release of mineral ions during decomposition. This can be influenced by the different N sources added to the composting substrate. Higher EC causes phytotoxicity and hence EC values of < 4 dS/m are preferred for composts (Yadav and Garg 2013). The EC values of different composts generated in the study were in safe limits (0.78 to 0.82 dS/m) and hence suitable for soil application. However, different composting methods could not significantly influence the EC of mature composts. C: N ratio regarded as the maturity index of composts is a key indicator of compost maturity. Different treatments had a significant impact on the final C: N ratio of mature composts. The best treatment in terms of significantly narrower C: N ratio (12.33:1) was T_8 which was comparable to T_6. The treatment with wider C: N ratio of mature compost was T_1 (co-composting of rice chaff with cow dung and poultry manure). This could be related to the initial C: N ratio of the substrates which followed the order; rice chaff > salvinia > water hyacinth > wild taro (Table 3). Co-composting could significantly reduce the C: N ratio of these substrates to the acceptable range of less than 30:1.

In the present study, C: N ratio of different composts varied from 12.33 to 15.79. The narrowing down of C: N ratio of different substrates could be related with the carbon usage during composting. Carbon is used up as an energy source for the metabolism of micro-organisms and the intense microbial activity results in a decrease in carbon content of the composting material. Simultaneous addition of N rich organic manures increases the N level as well as the activity of N fixing bacteria (Raj and Antil 2011). Because of these reasons C: N ratio of mature composts narrow down to the desired level. As the nitrogen content of organic manures used for composting increases, the C: N ratio of the final composts narrow down rapidly. The nitrogen content of different manures used in the current study followed the order; goat manure (2.30) > poultry manure (1.79) > cow dung (1.12). The treatments with cow dung and goat manure as organic sources had higher nitrogen content as compared to the poultry manure-cow dung combination thereby reducing the C: N ratio to a narrow value. This in confirmation with the results of a composting experiment done at KAU (Athira et al 2021).

The C: N ratio of final composts in the current study followed the order; wild taro compost < water hyacinth compost < salvinia compost < rice chaff compost. Sembera et al (2019) observed that the final C: N ratio of wild taro compost ranged between 12.4 to 13.4. Zuhair et al (2022) reported that taro leaves composted using cow dung as nitrogen source could result in a C: N ratio of 11.23 for mature compost. Similarly, the C: N ratio of water hyacinth considerably narrowed down up to 14.2 at the end of composting (Sasidharan et al 2013). In the current study, rice chaff compost recorded wider C: N ratio. Liu et al (2011) reported similar values of C: N ratio of rice chaff compost as 16.7.

Nutrient status of mature composts: Different co-composting treatments had a significant influence on the content of macro nutrients and all the composts had an enhanced nutritional value compared to the substrates used. The nitrogen content (%) of different substrates used in the study were rice chaff (0.9), salvinia (0.73), water hyacinth (1.07) and wild taro (0.63) (Table 3). The best treatment in terms of significantly higher nitrogen content was T_6. As compared to other substrates used in the study, the content of nitrogen, phosphorus and potassium were higher in water hyacinth. This was also reflected in the final nutrient status of water hyacinth compost. Addition of nitrogen rich goat manure along with cow dung enhanced the final nutrient content of water hyacinth compost (T_6). Composts with higher nitrogen content could be generated from water hyacinth by co-composting it with goat manure (Napoleon et al 2021). Among the co-composting treatments, T_4 recorded the least nitrogen content. This could be attributed to the lower nutrient status of wild taro and the higher moisture content of this weed. As the moisture content is high, the

biomass addition and hence nutrient deposition was less. The leaching loss of nutrients during the wilting period of wild taro accounting to higher moisture content could also be related with this.

The initial phosphorus status (%) of substrates used were; rice chaff (0.49), salvinia (0.61), water hyacinth (0.67) and wild taro (0.25). The best treatment in terms of significantly higher phosphorus content was $T_{6.}$ .This might be due to the higher P content in water hyacinth over other substrates. Sasidharan et al (2013) reported the phosphorus content of water hyacinth compost as 2.72 per cent. Beesigamukama et al (2018) obtained P rich composts from water hyacinth by way of co-composting with poultry manure. The lowest phosphorus content was recorded in the co-composting treatment T_4. As the water content in wild taro is high, a large amount of nutrients is lost through leaching thereby reducing the nutritional content of final compost. In a composting trial, Sembera et al (2019) reported that the content of phosphorus in wild taro compost ranged between 0.31 to 0.43 per cent only. Composting wild taro leaves with cow dung generated compost with lower phosphorus content of 0.45 per cent (Zuhair et al 2022). The total K content was higher in T_6 and was comparable to $T_{5.}$ The enhanced content of potassium in these co-composting treatments can be related with the initial higher potassium content of the substrates; water hyacinth (1.18) and rice chaff (0.97). In a composting trial, co-composting of water hyacinth resulted in a higher potassium content of 3.10 per cent (Seoudi 2013). Water hyacinth could be effectively used as a substitute for potash because of its richness in potassium content (Alam et al 2017). Similar results of higher initial K content in water hyacinth and generation of K rich composts were reported by Beesigamukama et al (2018). Abubakari et al (2019) reported that the rice husk is a potential source of potassium and addition of nutrient rich manures further improved the potassium content of the composts generated from it. Tyopine and Aondoaver (2014) concluded that potassium rich manures can be produced from rice husk. Among the co-composting treatments, the lowest potassium content was recorded in T_4 which is attributed to the lower content of potassium in wild taro stalks utilized for composting.

CONCLUSION

The aquatic weeds and rice chaff, associated with rice based integrated farming system can be effectively recycled for generating good quality composts. These substrates can be composted easily by the common and locally available manures such as cow dung, poultry manure and goat manure. Co-composting of wild taro with cow dung and goat manure in the ratio 4:1:1 ratio on volume basis resulted in the generation of composts rapidly and with significantly narrower C: N ratio, comparable to water hyacinth compost prepared from cow dung and goat manure. However, the recovery percentage of wild taro compost was significantly lower when compared to other treatments. Co-composting of rice chaff with cow dung and poultry manure recorded the highest recovery percentage; but the time taken for compost maturity was longer. Regarding the content of major nutrients, co-composting of water hyacinth with cow dung and goat manure in the ratio 4:1:1 (v/v) recorded significantly higher N, P and K content. From the view point of a farmer, co-composting of water hyacinth with cow dung and goat manure can be recommended as this compost can be generated within a shorter period of 66 days with significantly narrower C:N ratio (12.58) and a fair recovery percentage (20.7 %) with significantly higher content of macro nutrients. The compost generated via co-composting was nutritionally better than farmyard manure and incorporating these bio resources in crop production can reduce the over-dependence on chemical fertilizers.

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Developments in Digital Image Processing Technologies for Weed Recognition and Herbicide Application

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Abstract: Weed competes with a crop for nutrition, soil and water and, reduces its yields drastically. Conventional methods i.e., manual, mechanical and chemical mean have some limitations in controlling weeds. With the advancement in electronics and computers, Site-Specific weed management (SSWM) can provide a solution for precise weeds management. SSWM technologies with basic components and functions are described. SSWM consists of 3 basic processes i.e., image sensing, crop-weed discrimination, and chemical application. Digital image processing plays a crucial role in crop-weed discrimination and fascinates chemical applications.

Keywords: SSWM, Weed management, Crop-Weed discrimination, Image processing, Smart herbicide applicator

Weed control is a serious issue in the agricultural production system. It drastically reduces crop yield via. competition for natural resources i.e., sunlight, water and nutrients (Ozlüoymak et al 2019). Various methods for controlling weeds i.e., manual, mechanical and chemical were used generally. Manual weeding methods were tedious, time-consuming and expensive. Mechanical methods using intercultural tools are effective only for inter-row weeding. Chemical methods are wieldy used and these are effective for both intra row and inter-row weeding. But the method involves thorough field coverage which nowadays contaminating natural resources i.e., soil, environment, and water (Savci 2012) and affecting human and animal health. Applying chemicals to only weed patches using site-specific weed management (SSWM) technologies can provide an effective and better solution. Real-time digital image processing integrated with spot herbicide applicator technology can save 75% herbicide (Yang et al 2003), 69.5% savings (Loghavi and Mackvandi 2008) as compared to the conventional chemical method. SSWM involves a three-step process i.e., image acquisition, digital image processing, and herbicide application. Ground-based sensing i.e., optical imaging from the ground has the ability for providing higher spatial resolution, real-time data processing over airborne remote sensing is not suitable for smaller areas because of its lower spatial resolution. This review paper discusses a general overview of the complete process of SSWM and provides recent technologies based upon the above process.

MATERIAL AND METHODS

Components of real time herbicide applicator : There are 3 steps for the complete process as mentioned earlier. Field image acquisition, crop – weed discrimination and herbicide applicator technology.

a) Image acquisition- Cameras
b) Digital Image Processing- Computer, microcontroller and image processing software
c) Smart spraying system- Tank, solenoid valve, sprays nozzles mounted on boom, microcontroller, and pump with motor.
d) Other accessories: Global positioning system (GPS) integrated with camera, vehicle.

Working of smart herbicide application system: A real-time smart application system applies herbicides to the weed patches without harming the crops using a machine vision system (Beckie et al 2019). It consisted of sensors which measure crop characteristic 'on the go'. Based on the information collected, a microprocessor processes the information and calculates the needs for inputs and transfer it to the controller system, which delivers the herbicides to the location measured by the sensors. The basic components of a complete herbicide applicator were discussed in section I. The other one is the off-road vehicle consisting of a Global positioning system (GPS) integrated with cameras. The entire system is mounted on an off-road vehicle such as a tractor, self- propelled machine or autonomous vehicles. As the machine moves over terrain, cameras mounted in it will capture the field images which will go to the computer having image processing software like MATLAB, Image Studio Lite, etc., where the image will be processed and the weed will be segmented out from the soil and crop. The GPS integrated with the camera will provide the location of weed coordinates.

The location of the applicator unit on the vehicle was initially set up by considering total time i.e., image processing and time required for the full opening of the solenoid valve. After receiving the weed signal, the microcontroller actuates the solenoid valve nearer to weed and herbicide would be sprayed on it. Thainimit et al (2012) had shown the typical layout of herbicide applicator system.

Field image acquisition: Image sensors are classified based on structure (complementary metal-oxide semiconductors (CMOS) and charge-couple devices (CCD)), spectrum covered (Visible (RGB) and Infrared), multispectral and hyperspectral image sensors. Examples-RGB cameras such as Kodak, Nikon, Sony, Samsung cameras, infrared (InfRec R500), multispectral cameras and hyper-spectral cameras (Delta Tee Enterprises 400-1000 nm). RGB cameras are cheaper, perceive information closer to eyes i.e. visible range and it is easy to interpret. Color-based soil-vegetation separation is based upon it. Infrared cameras provide information which our eyes can't perceive, sometimes the information provided is also difficult to interpret. Multispectral cameras provide larger information in continuous bands with a broad range of the spectrum. It has a limited number of bands (3-10) from ultraviolet, visible and infrared range. Hyper-spectral bands also provide information in ultraviolet, RGB as well as infrared range, but in a narrow range, continuous bands, the number of bands are much more than multispectral i.e. (few 100-1000), appropriate bands can be used to distinguish crop, weed and soil.

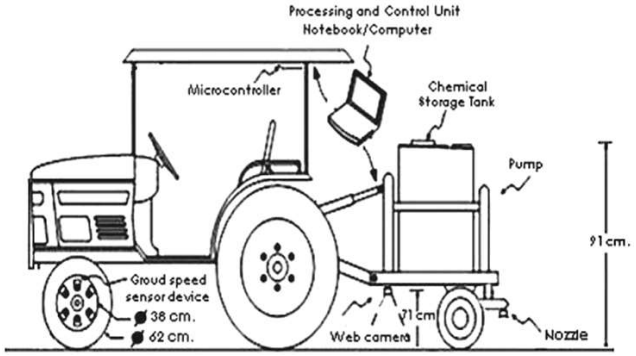

Fig. 1. Layout of the herbicide applicator system (Thainimit et al 2012)

Digital image processing for crop weed discrimination: Digital image processing provides an efficient approach for segmenting crop-soil and weed images acquired from the cameras. It generally follows a four-step procedure for crop-weed discrimination i.e., pre-processing, vegetation segmentation, feature extraction, and classification. In this image taken from the cameras were preprocessed for removing noise, resizing and image enhancement. Then a basic threshold-based segmentation process for separating green plant using the excessive green index, normalized difference index, etc., were performed for creating vegetation segmented regions. This will go as an input to the next step, where suitable features such as biological morphology, visual texture, and spectral features were extracted from the vegetated segment region. After this vegetated segmented region is classified by performing thresholding techniques on the obtained binary image. Another approach for classification except thresholding is a machine vision-based learning algorithm includes artificial neural network, principal component analysis which automatically extracts features from vegetated segment regions and classified it into groups.

Smart herbicide spraying system: The spraying control system consisted of a tank, solenoid valve, sprays nozzles mounted on boom, microcontroller, and pump with motor. The microcontroller receives the response from the computer about the resulting processed image**.** If the classification steps results, output as a weed. The micro-controller

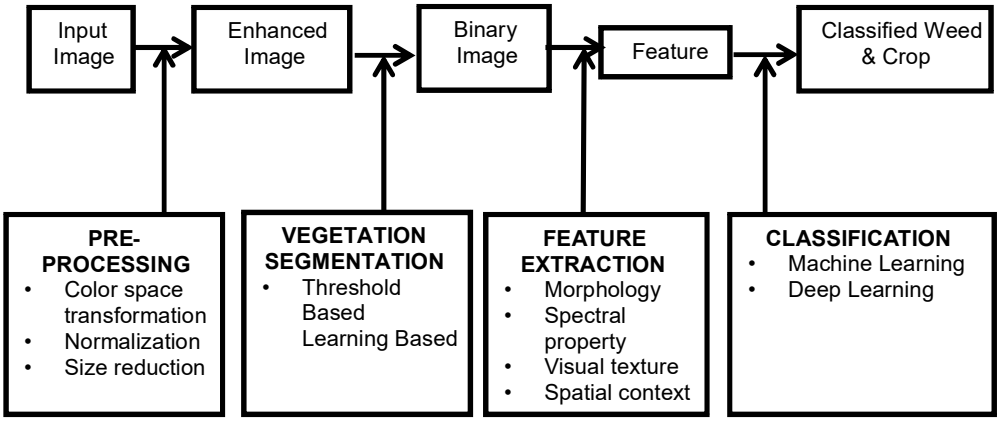

Fig. 2. Flow chart of the weed-crop classification system (Weis and Sokefeld 2010)

provides an open signal to the solenoid valves near to the weed. Weeds spatial coordinates were obtained from the Global Positioning System (GPS) integrated with the camera. Then a continuously operated pump will supply the chemicals to the nozzles in near to weed patch and spraying will be done (Blue river technology). In some machine's applicator is provided with a moving mechanism in the lateral direction, that reaches to weed location and applies a jet to the weed patches (Eco-Robotix).The typical components of smart herbicide spraying system are shown in Figure 3 (Sabanci and Aydin 2017).

Advance technologies in herbicide application: Tian et al (2000) developed a site-specific precision sprayer based on machine vision. The system hardware consisted of cameras, portable computer, 16-bit controller, solenoid valves, speed sensor, and high-speed CX-100 frame grabber. The prototype system used on/off control and a constant flow rate through each nozzle for savings the herbicides. The system was kept ON when the weed density was above the threshold of 1.5% weed leaf coverage. The current system design could save about 48% herbicide. The image processing time and on/off spray decision time was 0.37s and 0.037s. Tangwongkit et al (2006) developed a real-time, variable rate herbicide applicator using machine vision system for performing inter- row weeding in sugarcane field. The components of sprayer were mounted on tractors and are consisted of wheel speed sensor, PWM circuit, web camera and controller (notebook computer), white plastic cover structure for light control, spray-boom with adjustable height and nozzle spacing, fan type nozzles (2 types), a 100- liter capacity tank, 2-support wheels for the rear frame, and a 12-volt DC electrical pump having maximum flow rate (3.785 l/min) at an operating pressure of 275.8 kPa. The software developed could be reprogrammed and the threshold levels could be adjusted according to the user preference. The sprayer was tested for 5 operational speeds; the prototype could spray on green targets correctly. The error of green color output from image processing was about 0.31% at SD +0.25. The application flow rate accuracy was about 91.7%. The applicator could save 20.6% herbicides over uniform application rate from 709l to 563l at 0.77ms^{-1}. For spot applications of agrochemicals in wild blueberry fields, Zaman et al (2011) developed a real-time variable rate sprayer. The system consisted of ultrasonic sensors, DICKEY-john Land Manager II controller, flow valve and solenoid valves mounted on a boom. The performance of developed sprayer was evaluated and compared with uniform spraying in two blueberry fields via. water sensitive papers were stapled to weeds. The percentage area covered with these 2 types of application ranged from 10.01 to 81.22% and from 5.39 to 72.67% in field 1 and field 2, respectively. The total lag time of 0.05s was observed between detecting tall weeds and spraying. Midtiby et al (2011) developed and tested a microspraying herbicide (glyphosate) applicator based on smart machine vision. The system consisted of a vision system (CMOS camera, computer), spray system (six nozzles and microcontroller) and a physical micro-sprayer. The process was tested with maize at a forward speed of 0.5 ms^{-1} two weed species (scentless mayweed and oilseed rape). The system effectively controls 94% oilseed rape, 37% of the scentless mayweed and didn't harm any maize plant. The lower control accuracy for scentless mayweed was due to timing problems of the micro-sprayer control system. The system was suitable for weed greater than 11×11 mm^2. Shirzadi et al (2013) developed and evaluated a real-time, trail- type, site-specific single inter-row herbicide application system based upon machine vision. The weeding control system consisted of an electronic circuit, an image acquisition and processing system, a rotary encoder, spray nozzles, solenoid valves and other hardware. The sprayer output was compared at three levels of weed coverage with traditional (uniform) spraying and no spraying (Control). The result indicates that each patch spraying plot used herbicide was proportional to the level of field weed coverage. The target application outcome in 75% less herbicide consumption compared to the conventional application, with similar effectiveness in weed removal. Esau et al (2014) tested an automated chlorothalonil (Bravo) fungicide variablerate sprayer for spot application in a wild blueberry. The system consisted of digital cameras, an 8-channel variable rate controller, a LMC, a pocket personal computer (PPC), eight solenoid valves, a servo valve, a flow meter and eight flat fan Teejet- TP8004E nozzles. The VR sprayer saves

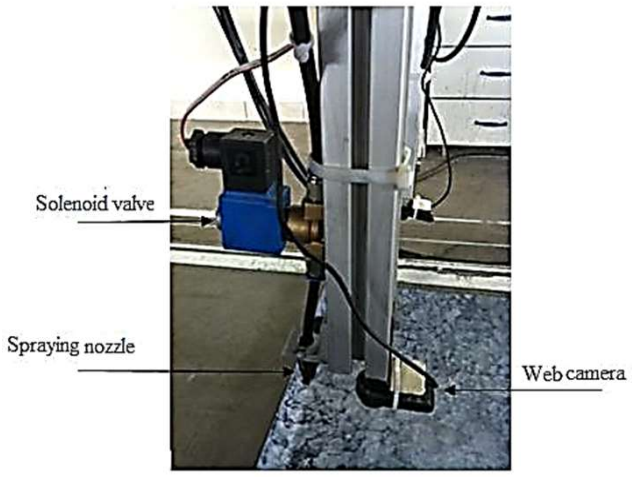

Fig. 3. Components of smart spraying system (Sabanci and Aydin 2017)

9.90 to 51.22% chemicals. The systems had an overall response time of 0.130 s at a 6 km h^{-1}. Tewari et al. (2014) developed a manually operated microcontroller-based roller contact-type herbicide applicator for inter-row crops using machine vision and image processing and the reduction in herbicide application rate for maize varied from 45.46 to 57.2% and was observed to be more than 40% for groundnut. The weeding efficiency was obtained an average 90.16% and 89.360% for groundnut and maize respectively.

Gonzalez et al (2016) developed and evaluated a real-time robotized patch sprayer for site-specific herbicide application. This system can be mounted on any autonomous vehicle such as a tractor. The smart spraying system consisted of 12 high-speed solenoid valve, spray nozzles, led indicator, central direct-injection system, water tank (200l), herbicide container, microcontroller, flow rate measurement sensors motor and battery. The entire system was mounted on a tractor with a laser system for detecting obstacles, RTK-GPS for precise location and machine vision for detection of weed. Rate of chemical injection was controlled by direct injection controller. The system performance was measured on a hard surface and it was observed that herbicide savings depend on weed density and its distribution. Herbicide saving closer to 66% can be achieved on winter crops having low to medium weeds.

Eco-robotics developed a solar operated, fully automated robotic weed killing device for row crops. The system weight was 130 kg and can be easily carried to the field with tractors. It consisted of a camera, moving mechanism, smaller herbicides tanks mounted on the mechanism, nozzles, navigation system using GPS and sensors, and solenoid valves. The applicator applies the precise micro-dose amount of chemicals to the individual weeds. The system had the capability to continuously operate for 12 hours per day. It saved 20 times more herbicides as compared to the conventional sprayer. Lab VIEW programming language for test an automated machine vision based spray robot for identification, tracking and spraying on artificial weeds consists of a camera (1280 × 720 pixels), a pneumatically controlled spraying unit (STNC, TC 2010–02), air compressor, premix tank, solenoid valve (12 V DC), flat-fan nozzle (110°, 0.2-gal min^{-1} flow rateat275.79kPa).

The unit moved back and forth automatically with the optical sensors (Pepperl+Fuchs, GLV18–8–450/115/120) mounted on both ends of the spray device. System performance capability was obtained at 5 speeds and three spraying durations. The results revealed site-specific spraying application saved an average 89.48, 79.98 and 73.93% volumes applied respectively in successive spray duration.

CONCLUSION

Digital image processing in collaboration with smart herbicide applicator technology has the greatest potential to save a huge amount of chemicals. Three steps were performed by SSWM technologies: image sensing, digital image processing for crop -weed discrimination and herbicide application on weeds. The technologies developed on the basis of these processes had the capability to save about 75 % of chemicals and able achieve more than 90% weeding efficiency. These technologies will help in preventing the environment, soil and groundwater resources for being contamination with chemicals. The application cost, labor requirement, and energy will also be saved by the amount of chemical applied. Various companies like Eco Robotix, John Deere working in collaboration with blue river technology had made successful prototypes, but they are not yet commercialized. Higher costs in initial developing stages and selective crops are some of the reasons. Multiple crops with different weeds type and varieties, variable rate metering based upon weed geometry and characteristic can be a problem need to address in future for the success of the machine.

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Effect of Growth Retardants under High Fertility Scenarios on Wheat Varieties

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***Abstract*:** Wheat is a leading cereal and its lodging under high fertility conditions is a main concern which is responsible for its lower productivity. The field experiments were conducted during the year 2018-19 and 2019-20 at Regional Research Station, Gurdaspur to evaluate effect of growth retardants under high fertility levels on wheat varieties to achieve yield maximization. The experiment was laid out in a split plot design with three replications. The treatments consisted of three fertility levels in main plots viz. FL1- Recommended Fertilizer Dose (RFD), FL2- RFD+Farmyard Manure @ 15 t ha^{-1}, FL3-150% RFD+ FYM (15tha^{-1}) + applications of growth retardants (GR) and five varieties i.e. WH 1270, HD 2967, DBW 187, HD 3086 and DBW 303 in sub plots. Results of the study revealed that treatment FL3 recorded significantly higher effective tillers, grains per earhead, grain yield, biological yield and harvest Index in wheat genotypes in comparison to treatment FL1. The minimum mean lodging score with the applications of growth retardants in FL3 was noticed even at high dose of fertilization. Maximum grain yield and biological yield were registered with treatment FL3 which was 7.4 and 15.7 %, 2.0 and 8.0 %, 5.1 and 7.1% over FL2 and FL1, respectively. Among different wheat varieties, DBW 187 recorded highest grain yield followed by HD 3086, DBW 303, HD 2967 and WH1270, respectively. Hence, DBW 187 is the promising variety as there was no yield decline under high fertility conditions.

Keywords: Fertility levels, Growth retardants, Varieties, Wheat, Grain yield

To maximize wheat crop yield, adoption of intensive crop management practices using high doses of fertilizers, especially nitrogen is in practice. The higher fertilizer dose sometimes causes lodging due to more height and more tillering and is a major concern in high yielding systems. Lodging limits both productivity and quality of produce. Yield losses due to lodging stress are 8–80% in wheat (Acreche and Slafer 2011). One of the main factors limiting wheat productivity is lodging, which has caused harvestable yield losses of up to 80% (Foulkes et al. 2011). As the plant height is recognized as valuable trait to impart lodging resistance in cereals, so, lodging can be minimized by shortening of the plant height (Lu et al 2014, Kuai et al 2015). Moreover, lodging stress is a complex phenomenon which is influenced by many factors, including high plant populations, excessive use of nitrogenous fertilizers, heavy rains, strong winds, storm or hail, topography, soil type, tissue damage by insects, and diseases (Ye et al 2016). The yield potential of high yielding genotypes of wheat under irrigated and high input rates could be achieved consistently and efficiently by finding suitable solutions of lodging problem. In this context, the use of growth retardants found to be most effective for managing the problem of lodging. Growth retardants are chemical substances that have the potential to alter structural or vital processes inside the plant by modifying hormone balance to increase yield, improve quality or facilitate harvesting through checking lodging especially in cereals (Zhang et al 2017). Although growth retardants can reduce the risk of lodging but limited literature is available on their effectiveness on the culm height, physical strength and possible effects on minimizing the lodging risk and grain yield in wheat crop genotypes under higher nutrition level. Therefore, the present study was conducted to elucidate the effect of different fertility levels and use of growth retardants on different wheat varieties with contrasting traits.

MATERIAL AND METHODS

Study site: The field experiments were conducted at the research farm of PAU Regional Research Station, Gurdaspur (32°03' N, 75°25' E; a.m.s.l 261 m) during *Rabi* seasons of 2018-19 (S1) and 2019–2020 (S2). The experiment site represents the north Punjab region which is sub-mountainous undulating zone falls under zone II of agro-climatic zones. Most of the precipitation (68%) at Gurdaspur, with a normal annual rainfall of 980 mm, is received during the monsoon months (July-September). A substantial precipitation is also received during the winter wheat season due to sub-tropical climatic phenomena called western disturbances (WD).

Experimental details: The soil of experimental field was

loam in texture with electrical conductivity (EC) of 0.19 dSm^{-1}, pH of 7.1, organic carbon (0.45 %), phosphorus (P) 20.0 kg ha^{-1} and potassium (K) 142.5 kg ha^{-1}. The experiments were conducted in split-plot design with three fertility levels i.e. FL1- Recommended fertilizer dose (RFD), FL2 – RFD+FYM (Farmyard Manure)15 t ha^{-1}, FL3-150% RFD+ FYM (15tha^{-1}) + applications of growth retardants(GR) in main plots and five varieties i.e. WH 1270, HD 2967, DBW 187, HD 3086 and DBW 303 in sub plots with three replications. The dose of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) were 125:62.5: 60 kg ha^{-1} and, 125: 62.5:60 kg ha^{-1} along with farmyard manure (FYM)15 t ha^{-1}, 187.5: 93.8: 90 along with FYM 15 t ha^{-1} in FL1, FL2 and FL3, respectively was applied before sowing of the crop whereas 1/3rd of N (urea), full P (diammonium phosphate), and K (muriate of potash) were applied at the time of sowing. The rest of the nitrogen was applied in two equal splits with one split application at first irrigation (crown root initiation stage) and second split application with second irrigation (maximum tillering stage). The different wheat varieties were sown on 20th October 2018 and on 22nd October 2019. The crop was sown in rows at 20 cm apart at depth of 4-6 cm. Growth retardant treatments included two sprays as tank mix application of Chlormequat chloride (Lihocin) @ 0.2% + tebuconazole (Folicur 430 SC) @ 0.1% of commercial product dose done at first node and flag leaf in each plot using knapsack sprayer on clear sunny days.

Growth parameters and yield attributes : The emergence count data was taken at 15 days after sowing by counting the number of plants per square meter from randomly selected 3 sites per plot and then average number of plants emerged per square meter. Other growth parameters and yield attributes were recorded at physiological maturity stage. The effective tillers were counted from per square meter from randomly selected 3 sites per plot and average was presented. Randomly ten ears were taken from each plot, threshed manually, counted, and averaged for calculating the number of grains per. A random sample of grain from each plot was taken. After harvesting manually, the bundles from each plot were weighed to record biological yield (kg/plot). At harvest time, the plant parameters recorded were plant height (cm), grain and straw yield (kg/ha). The plant's height was measured in cm using a metre scale from the base of the plant. The plants from each net plot were harvested and grains were separated by threshing, grain and straw yields obtained in each net plot were weighted (kg) and further it was calculated on the hectare basis (kg ha^{-1}).

Determination of lodging score: The percentage of the plot area lodged to the total area of the plot was recorded and presented as percent lodging (0–100%) of the plot. Lodging score was calculated based on the integral effect of lodging percentage and lodging.

$$\text{Lodging score} = \frac{\text{(Lodged area/Net plot area)} \times \text{angle of lodging}}{90} \times 100$$

RESULTS AND DISCUSSION

Effect of growing seasons on wheat growth and yield: A significant variation in emergence count, plant height and number of effective tillers of wheat between the seasons was observed (Table 1). However, number of grains per year was at par in both seasons as it is less influenced by environmental factors being a genetic character. The grain yield, biological yield and harvest index of the crop was significantly lower in S2 compared to S1 (Table 2). The percent deviation in yield and biomass production of wheat was - 26% and -23% in S2, respectively. In contrast, the lodging score was significantly higher in S2 irrespective of nutrient management dosages and wheat varieties. The favourable weather conditions during S1 played a major role in wheat crop growth and yield (Fig. 1). The S2 was warmer as compared to S1 during major growth phases which hampered the grain filling at later stages and produced less ear heads, grain yield and biological yield. The maximum day time air temperature coincides with heading to anthesis period (February month) of wheat, during S2, it was 3.1°C higher compared to S1. Higher day temperature might have affected the pollen growth and anthesis in S2 and hence produced less grain yield and low yield attributes (Djanaguiraman et al 2020). The total rainfall received during the wheat seasons was 364.7mm and 404.4 mm in S1 and S2, respectively. The rainfall during grain filling/maturity (March and April month) was 484% higher during S2 which led to more crop lodging and thus reduced wheat yield and harvest index during the season as compared to S1 (Niu et al 2016). The average bright sunshine hours were also higher during S1 (5.1) compared to S2 (4.0). Higher sunshine during S1 provided more photosynthetically active radiation (PAR) to accumulate more dry matter and grain yield (Ahmed and Hassan 2011).The maximum HI was during 2018-19 and it was significantly higher than 2019-20.

Effect of fertility levels and growth retardants on yield attributes of wheat: The treatment FL1 recorded significantly higher emergence count as compared to treatment FL3 but was at par with FL2. At harvest, FL2 recorded significantly higher plant height than FL1 followed by FL3. In the treatment FL3, minimum plant height was observed which might be due to spray of growth retardants at first node and flag leaf stage. Application of growth retardants in treatment FL3 significantly reduced plant height by 9.9 cm

and 12.3 cm when compared to FL1 and FL2, respectively. The reduction in plant height also helped in lodging reduction and had a significant effect on effective tillers even at high nutrition. About 11.2 and 13.6 per cent higher effective tillers were recorded in treatment FL3 over FL2 and FL1, respectively. Maximum grains per ear head (48.0) were also in FL3 and were significantly higher than FL1 (44.2) and were at par with FL2 (46.3).The FL3 treatment recorded 7.41 and 15.7% higher grain yield than FL1 and FL2, respectively. The higher grain yield in FL3 treatment was due to the production of more effective tillers and grains per ear head. Balanced nutrition throughout growth stages of a plant, enables it to assimilate sufficient photosynthetic products and enhance dry matter accumulation (Khan et al 2014 and Yadav et al 2017). HI was significantly higher in treatments FL1 and FL2 as compared to FL3 whereas treatments FL2 and FL3 remained at par with each other.

Response of wheat genotypes to fertility levels and growth retardants: The emergence count did not vary significantly with respect to different wheat varieties. The wheat variety HD 3086 recorded minimum height and was significantly different in height from other varieties. However, height recorded in other varieties was at par with each other. Maximum effective tillers were recorded in HD 2967 and the

Table 1. Effect of high fertility levels and growth retardants on agro-morphological parameters

Treatment	Emergence count ($n\ m^{-2}$)	Plant height (cm)	Effective tillers ($n\ m^{-2}$)	Grains per earhead(n)
Seasons (S)				
2018-19	208.43a	90.16a	445.75a	44.55a
2019-20	180.17b	85.71a	338.61b	44.55a
Nutrient management level (FL)				
RFD (FL1)	200.35a	90.41b	372.55c	44.23b
RFD+FYM (FL2)	194.75ab	92.89a	380.64b	44.23b
150%RFD+FYM+GR (FL3)	187.8b	80.51c	423.35a	46.28ab
Varieties (V)				
WH 1270	192.47a	88.02a	393.52b	43.52c
HD 2967	193.42a	88.36a	410.14a	43.52c
DBW 187	193.28a	89.13a	385.72bc	43.97c
HD 3086	200.31a	84.11b	393.47b	45.33bc
DBW 303	192.03a	90.06a	378.06c	47.66b

Same alphabet in column do not differ significantly, Duncan Multiple Range Test (p-0.05)

Table 2. Effect of high fertility levels and growth retardants on wheat yield, yield attributes and lodging score

Treatments	Grain yield ($q\ ha^{-1}$)	Biological yield ($q\ ha^{-1}$)	Harvest index (%)	Lodging score
Seasons (S)				
2018-19	90.01a	235.41a	38.31a	0.47b
2019-20	66.55b	181.38b	36.88b	7.6a
Nutrient management levels (FL)				
RFD (FL1)	72.59c	199.15b	39.08a	4.07a
RFD+FYM (FL2)	78.21b	210.87ab	37.21b	4.03a
150%RFD+FYM+GR (FL3)	84.04a	215.15a	36.5b	4a
Varieties (V)				
WH 1270	76.09b	194.12b	39.34a	3.56b
HD 2967	77.23b	217.79a	35.31c	4.44a
DBW 187	82.23a	220.43a	37.21b	4.67a
HD 3086	78.29b	197.02b	39.77a	3.83b
DBW 303	77.56b	212.61a	36.36bc	3.67b

Same alphabet in column do not differ significantly, Duncan Multiple Range Test (p-0.05)

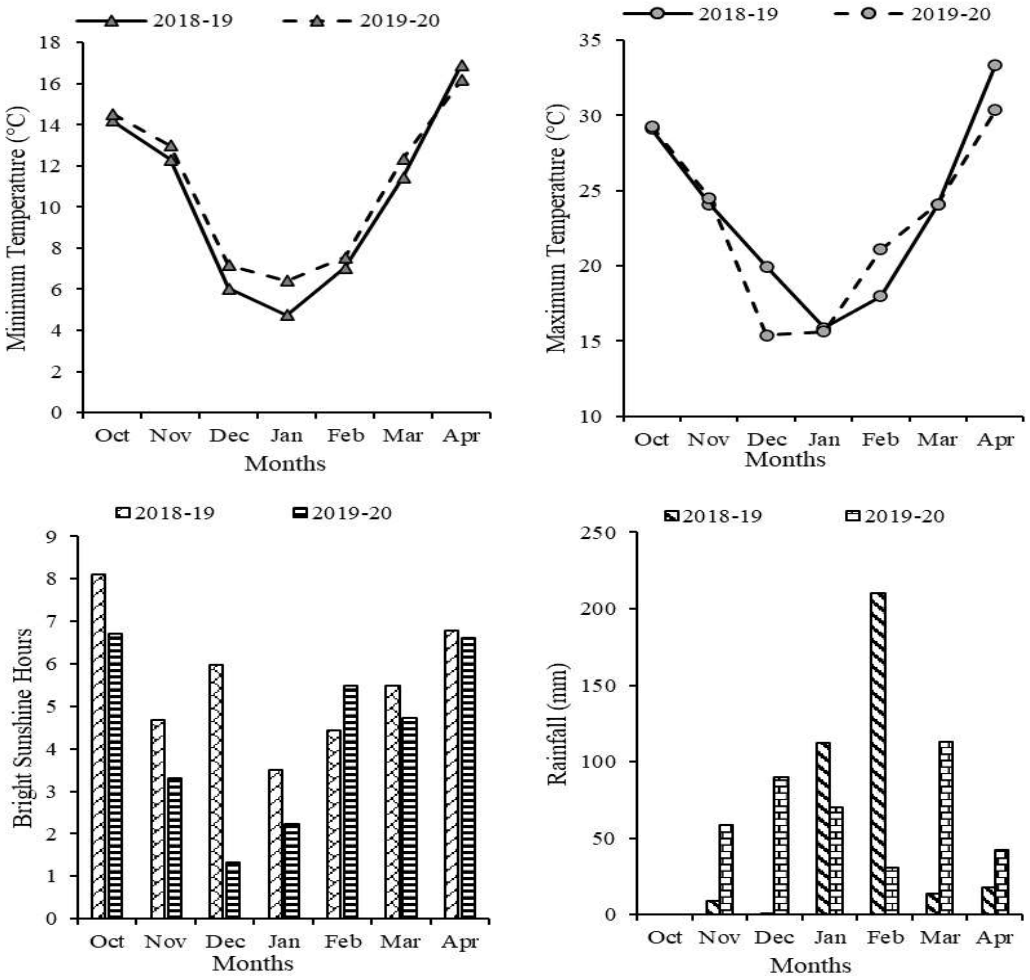

Fig. 1. Weather parameters during *Rabi* 2018-19 and 2019-20

other varieties WH 1270, HD 3086 and DBW 187 produced tillers which were at par to each other. Lowest earhead count was observed in variety DBW 303, but it recorded significantly higher grains per earhead as compared to other varieties. The highest grain yield and biological yield was recorded in wheat variety DBW 187. An increase of 5.12,5.72,6.47 and 8.01 % in yield of DBW 187 was observed over HD 3086, DBW303, HD 2967 and WH 1270, respectively. The variety HD 3086 recorded maximum HI (39.7%) followed by WH 1270 , DBW 187, DBW 303, and HD 2967.

Effect of fertility levels and growth retardants on lodging score of wheat: In the second year more lodging score (7.6) was observed as compared to first year (0.47) whereas different fertility level treatments recorded almost similar lodging score. Application of growth retardants in FL3, resulted in shortened plant height even at high fertilization and helped in reducing lodging score. Maximum lodging score was observed in variety DBW 187, might be due to more biological yield of crop.

CONCLUSIONS

The high fertility treatment 150% RFD+ FYM (15 t ha^{-1}) + applications of growth retardants recorded the highest grain yield and DBW 187 is the most suitable variety under high fertility conditions since there was no yield decline in the presence of high fertility.

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Response of *Mushk Budji* Rice to Microclimate Modifications under Temperate Environmental Conditions

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Abstract: Field experiment was conducted during *Kharif*-2021 at Division of Agronomy, SKUAST-K, Wadura with three dates of transplanting *viz*. 05th June, 15th June and 25th June and three crop geometries *viz*., 15 cm x 10 cm, 15 cm x 15 cm and 20 cm x 15 cm. The study used microclimatic modifications by adjusting the sowing time and crop geometry. The early transplanted treatment (5th June) did better than those transplanted in latter weeks of June in terms of growth, phenology, grain yield and low blast disease incidence of scented rice-*MushkBudji*. Variations among crop geometries were also observed, with crop spacing 20 cm x 15 cm required more time to attain different phenological stages thus producing a higher yield at harvest and low blast disease incidence of rice-*MushkBudji*. Moreover, statistically significant interactions between the transplanting dates and crop geometries on grain yield were identified, where early transplanted rice crop (5th June) at spacing 20 cm x 15 cm (T_1S_3) proved to be the better combination for maximum yield. The study concluded that early transplanting (5th June) with spacing 20 cm x 15 cm (S_3) realized higher growth, yield parameters and low blast disease incidence of rice- *MushkBudji* under lower altitude belts (1590 amsl) of Kashmir.

Keywords: Rice, Sowing environment, Crop geometry, Phenology and yield

Scented rice, traditionally grown by farmers constitutes about 4% of total rice cultivation grown across the globe. Cultivation of aromatic rice is very remunerative as it fetches a higher price compared to other rice indicating better income of the cultivators. Despite 12% growth of scented rice globally, its production is declining in India. However, the area under Basmati rice in major grown states of India is around 1.938 million hectares. Haryana is leading with an area of 0.84 million hectares, followed by the Punjab (0.5501), Uttar Pradesh (0.463) (APEDA 2019). The temperature of Kashmir valley is naturally feasible for the local special aromatic rice landraces including more than 100 documented landraces of Japonica type (Parry et al 2008). Among them, *Mushk Budji, Kamad, Nun-boeul,* and *Zag* are the most popular and have a great commercial demand because of their aroma and taste. Therefore, these varieties are an effective way to stabilize a farmer's income. However, in the past three decades, the land has dwindled and receded drastically (MRCFC, SKUAST-K report, 2014). Rice blast disease is a major limiting biotic factor and is endemic to most rice growing areas of J&K. Blast-conducive environmental conditions during the crop season, have drastically affected the production, causing massive economic loss. The crippling nature of this disease makes it a hazardous biological weapon. Most of the indigenous landraces are highly susceptible to the disease. A total loss of 70% yield has been reported due to the outbreak of rice blast disease (Ali et al 2009).

The study used microclimatic modifications by adjusting the sowing time and crop geometry. The study aimed to manage the climatic factors on a microscale, to create an environment favorable for plant growth. The best outcome of rice cultivation is directly proportional to the appropriate temperature range, which can be managed and controlled by sowing at the proper time. Optimum plant spacing is another important factor that ensures proper plant growth (Basha et al 2017). Field-level adjustments enable us to standardize management practices to control blast disease severity. Although chemical control of the disease is feasible, it is economically impractical for resource poor farmers and is environmentally undesirable. Thus, the present study aims to determine the optimum sowing date and crop geometry and its effect on growth, phenology, yield, and blast disease incidence of aromatic rice-*Mushk Budji* grown under lower altitude conditions of Kashmir valley.

MATERIAL AND METHODS

The field experiment was carried out at Division of Agronomy Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura (34°21'N and

74° 23' E), Sopore. The experiments were conducted during the *Kharif* Season of 2021 at lower altitude (1590 meters). The treatments included three transplanting dates viz. T_1: June 5 (early), D_2: June 15 (mid) and D_3: June 25 (late) and three crop geometries viz. S_1: 15 cm x 10 cm, S_2: 15 cm x 15 cm and S_3: 20 cm x 15 cm. The experiment was laid out in a factorial randomized complete block design (RCBD) with three replications. The soil of the experimental site was silty clay loam in texture, neutral in reaction with low available nitrogen (158.92 kg/ha), medium available phosphorus (158.92 kg/ha) and medium available potassium (132.71 kg/ha). Weather data were obtained from a weather station set up at the experimental site during the period of May to September of 2021, indicating that the crop had experienced mean maximum and minimum temperature of 29.6°C and 13.5°C, average precipitation of 9.35 mm and mean maximum and minimum relative humidity of 82.6 % and 52.6 % respectively during the growth period (Fig. 1). Applied well decomposed FYM @ 5,000 kg/ha at the time of land preparation. Seedlings of 30 days were uprooted carefully from nursery beds on the defined and decided dates and were transplanted in the experimental field with 2-3 seedlings per hill at different spacings. Applied Urea, DAP, MOP and ZnSO4 @ 50, 90, 34 and 15 kg/ha at the time of transplanting and top dose of Urea @ 20 kg at 25 days after transplanting. Plant protection measures were also taken by using only two chemical sprays of fungicides (Total four sprays recommended by SKUAST-K). First spray of Carbendazim @ 1 g/litre of water was after 30 days after transplanting. Second spray of Mancozeb @ 3 g/litre of water was applied 20 days after first spray. The data on growth (plant height, leaf area index), phenology, yield attributes viz. number of effective panicles/m^2, panicle length, panicle weight, 1000-grain weight and yield of rice were recorded following standard procedures. For analysis of variance, data was analyzed using a factorial randomized block design using the OP-STAT data analysis package (Sheoran et al 1998).

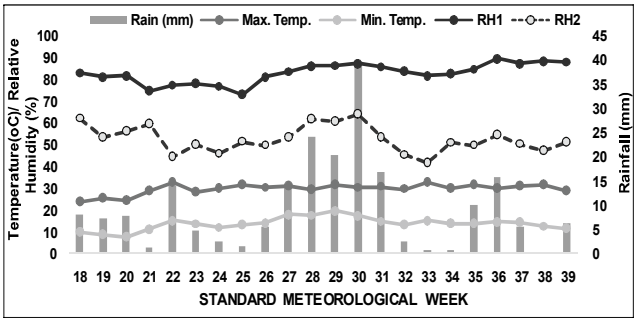

Fig. 1. Weather conditions prevailed during the crop growth period of *Kharif* 2021

RESULTS AND DISCUSSION

Rice growth parameters: Various transplanting dates and crop geometries caused substantial variations in growth parameters. The crop transplanted early recorded maximum plant height and LAI compared to mid and late transplanting (Table 1). The crop sown late in the season experienced comparatively lower temperatures during later growth stages had shorter growing period due to photoperiodic response and thus plant height and LAI remained low (Bashir et al 2010, Sulieman et al 2014 and Osman et al 2015). The maximum plant height and LAI was recorded in 15 cm x 10 cm, followed by 15 cm x 15 cm and minimum plant height and LAI was recorded in 20 cm x 15 cm (Table 1). To get more radiations, plants grow faster and get more height as supported by Kumar and Kumar (2018). Bashir et al (2010) revealed that leaf area, total dry matter, absolute growth rate increased with increasing spacing, while leaf area index showed a reverse trend (Pokharel 2018).

Rice yield attributes: Yield attributes viz. number of

Table 1. Growth and yield attributing characters of rice-*MushkBudji* as influenced by transplanting date and crop geometry

Treatments	Plant height (cm)	Leaf area index	No. of effective tillers /m^2	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)
Transplanting dates						
5 June	128.83	2.20	317.52	20.27	2.79	19.09
15 June	123.99	2.12	306.16	18.46	2.51	17.91
25 June	112.72	2.00	299.67	17.07	1.45	16.17
CD (p=0.05)	4.52	0.04	14.14	1.13	0.30	0.51
Crop geometries						
15 cm x 10 cm	125.55	2.15	294.07	17.17	1.98	16.70
15 cm x 15 cm	123.64	2.12	313.67	18.51	2.32	18.13
20 cm x 15 cm	116.36	2.04	315.62	20.11	2.44	18.33
CD (p=0.05)	4.52	0.04	14.14	1.13	0.30	0.51

effective tillers/m^2, panicle length, panicle weight, and 1000-grain weights in crop transplanted on June 5 were significantly superior over late transplanting (June 15 and June 25) (Table 1). This might be due to favorable environmental factors and prolonged overall growing season which increased the accumulation of carbohydrates in plants, ultimately the yield attributes (Akbar et al 2010). There were significantly higher number of yield attributing characters under 20 cm x 15 cm compared to 15 cm x 15 cm and 15 cm x 10 cm (Table 1). Wider spacing showed an advantageous factor for better development of panicles, hence more panicle length, panicle weight. Efficient utilization of growth resources, less intra-species competition coupled with higher availability of nutrients among widely spaced crop plants may be ascribed the reason for superiority of yield components of rice (Pawar et al 2017).

Rice phenology: The crop transplanted early prolongs maximum tillering, panicle initiation, anthesis, and physiological maturity compared to crop transplanted in mid to end June (Fig. 2). Considerably lower temperature during the early growth stages resulted in the prolonged vegetative phase in case of early transplanting date (Abhilash et al 2017). Crop geometries also reacted differently for number of days required to attain distinct phenological stages (Fig. 2). Rice transplanted at spacing 20 cm x 15 cm took a greater number of days to reach maximum tillering, panicle initiation, anthesis and physiological maturity than spacing 15 cm x 15 cm and 15 cm x 10 cm. The reason being more of crop growth and nutrient availability at wider spacing than the closer spacing (Rasool et al 2013).

Rice yield: Crop transplanted early recorded significantly higher grain yield (4.14 t/ha), straw yield (9.52 t/ha), and harvest index (30.23%) as compared to mid to late June transplanting (Table 2). Late transplanted rice has always lower yield than normal transplanted rice which may be due to improper root growth and development causing less absorption of nutrients from soil, shortened duration of various phenophases of crop development, low temperature during grain filling and grain maturation time (Kushwaha 2018). Concerning crop geometries, 20 cm x 15 cm recorded a significantly higher yield for grain (3.95 t/ha) and straw (9.35 t/ha) and the harvest index (29.50%) as compared to 15 cm x 15 cm and 15 cm x 10 cm crop geometries (Table 2). The higher yield in wider spacing could be due to higher number of effective tillers/m^2 and number of filled grains/panicle. Optimum spacing ensures the plant to grow in their both aerial and underground parts through efficient utilization of solar radiation and nutrients, plants had linearly increasing effect on the performance of individual plants (Thavaprakash et al 2017).

Interaction effect: Interaction effect of transplanting dates and crop geometries on grain yield of rice was significant (Fig. 3). The interaction effect between transplanting date and crop geometry for grain yield indicated that early transplanted crop with spacing 20 cm x 15 cm produced

Table 2. Yield and harvest index of rice-*MushkBudji* as influenced by transplanting date and crop geometry

Treatments	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Transplanting dates			
5 June	4.14	9.52	30.23
15 June	3.71	9.09	28.93
25 June	2.83	8.45	25.13
CD (p=0.05)	0.18	0.34	1.64
Crop geometries			
15 cm x 10 cm	3.11	8.65	26.40
15 cm x 15 cm	3.63	9.06	28.39
20 cm x 15 cm	3.95	9.35	29.50
CD (p=0.05)	0.18	0.34	1.64

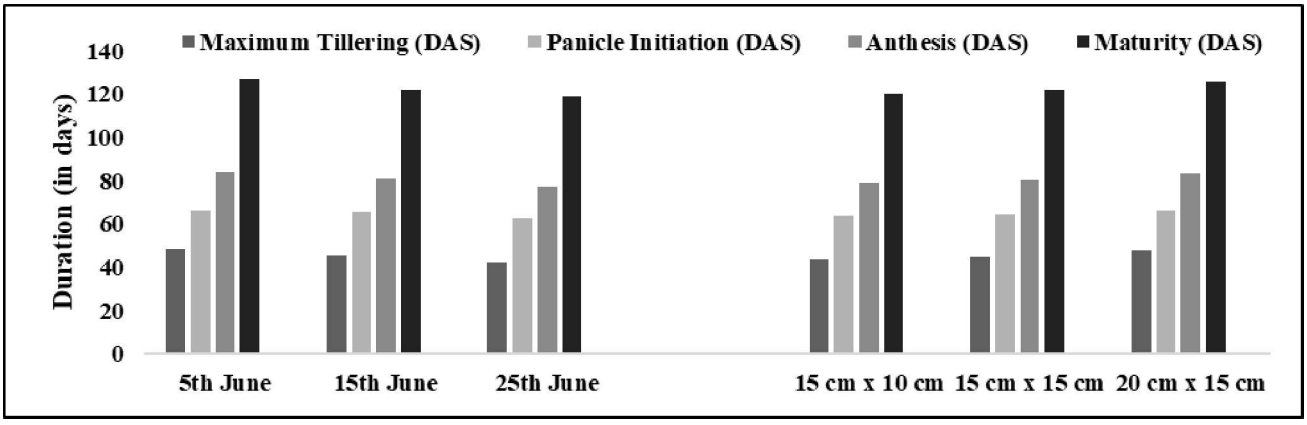

Fig. 2. Days taken to phenological stages of rice- *MushkBudji* as influenced by transplanting dates and crop geometry

significantly higher grain yield (4.67 t/ha) than other treatment combinations. Fayaz et al (2015) and Yumnam et al (2021) also reported significant interaction between planting date and spacing.

Rice blast disease incidence and intensity : The rice blast development is influenced by temperature and humidity. The different dates of transplanting had a significant effect on blast disease incidence and intensity (Table 3). The early transplanted crop had least leaf, neck and node blast incidence and leaf blast intensity score followed by mid transplanted crop while the maximum blast incidence and intensity score was recorded by late transplanted crop. Early planting date helped susceptible cultivars to escape from severe infection of blast because of low temperature and low humidity levels. Higher humidity levels and frequent rainfall create environmental conditions conducive for rice blast infection. Both growth and sporulation increased up to a temperature (27°C) and decline further in response to increased or decreased with temperature (32°C and 22°C) as reported by Rajput et al (2017). Crop geometry showed a significant effect on the blast disease incidence and intensity score. Maximum blast disease incidence and intensity score was under closer spacing 15 cm x 10 cm followed by 15 cm x 15 cm; however, the minimum blast incidence and intensity was under wider spacing 20 cm x 15 cm (Table 3). The density of the plant canopy directly impacts the susceptibility of plant tissues to the pathogen, creating a favorable environment for disease development. Canopy structure, radiation, air circulation, soil temperature, and wind are the primary factors that determine the moisture profile under the canopy, which in turn influences disease development, especially through plant spacing and canopy gaps that enhance ventilation and reduce canopy wetness. These findings align with those reported by Sopialena and Palupi (2017) and Nugroho et al (2021).

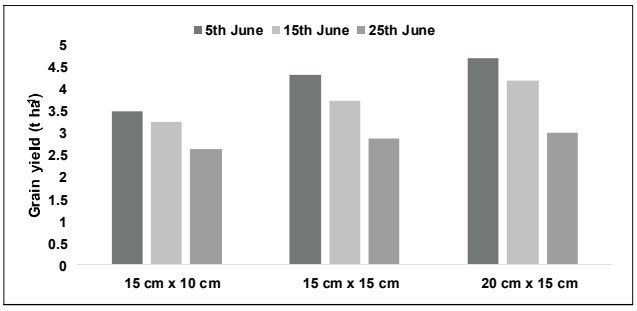

Fig. 3. Interaction effect of transplanting date and crop geometry on grain yield

Table 3. Effect of transplanting dates and crop geometry on diseases of rice-*MushkBudji*

Treatments	Leaf blast incidence (%)	Leaf blast intensity (%)	Neck blast incidence (%)	Node blast incidence (%)
Transplanting dates				
5 June	28.33	14.60	15.36	12.13
15 June	34.03	18.49	20.15	16.12
25 June	39.69	25.31	25.77	22.51
CD (p=0.05)	2.21	2.29	2.39	2.43
Crop geometries				
15 cm x 10 cm	37.75	23.89	24.73	21.21
15 cm x 15 cm	33.43	18.31	19.18	15.98
20 cm x 15 cm	30.87	16.19	17.37	13.58
CD (p=0.05)	2.21	2.29	2.39	2.43

CONCLUSIONS

This study showed how rice-*MushkBudji* under different transplanting dates and crop geometry responded regarding their growth, phenology, and yield. Apart from that, we were able to see the impact of agronomic manipulations upon the blast disease incidence, achieved by altering the crop geometry. Wider spacing 20 cm x 15 cm between plants creates a dilution effect, resulting in better disease control and reduced the number of two chemical sprays as recommended by SKUAST-K. The better growth, higher grain yield and low blast disease incidence of scented rice-*MushBudji* under lower altitude belts (1590 amsl) of Kashmir can be achieved by transplanting the rice- *MushkBudji* earlier in the season during 23rd standard meteorological week (4th June -10th June) with the spacing of 20 cm x 15 cm.

AUTHORS CONTRIBUTION

Ifrah Taranum is PG scholar who conducted research, S. Sheraz Mahdi has conceptualized the research idea, Rukhsana Jan assisted in field experiment and data observation, Fayaz Ahmad Bahar has assisted in manuscript writing, Amal Saxena, assisted in manuscript writing and final editing, Shaista Nazir assisted in soil sampling & analysis, Fehim Jeelani Wani planned Layout of field experiment and data analysis and Bhagyashree Dhekale helped in designing of field experiment and data tabulation and analysis.

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Performance of Integrated Nutrient Management in Soybean (*Glycine max* L.) under Rainfed Conditions

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***Abstract*:** Field experiment was conducted during *Kharif*-2020 at Division of Agronomy, Faculty of Agriculture, SKUAST-K, Wadura to study the performance of soybean (*Glycine max* L.) to integrated nutrient management under rainfed conditions of Kashmir. The experiment comprised of 14 treatments *viz.*, Control (T_1), 100% RDF (T_2), FYM @ 10 t/ha (T_3), Vermicompost @ 2.5 t/ha(T_4), Poultry manure @ 2.5 t/ha(T_5), Vermiwash @ 10% (T_6), *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_7), 100% RDF + *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_8), *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* + Vermiwash @ 10% + 50% RDF (T_9), Vermicompost @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{10}), Poultry manure @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{11}), FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}),75% RDF + FYM @ 5 t/ha(T_{13}) and 50% RDF + FYM @ 5 t/ha(T_{14}). It was revealed that the treatment T_{11} produced significantly greater seed yield (27.35 q/ha) than other treatments, however, T_{10}, T_{12} and T_8 were at par with T_{11}. Moreover, T_{11} was found superior to rest of the treatments in growth parameters, plant height (124.78 cm), leaf area index (3.16), dry matter accumulation (55.97 g/plant), as well as the yield attributing character, number of pods/ plant (88.65). The highest net returns ((₹93,214) were recorded in T_{11} while as the highest B:C ratio (2.81) was observed in T_{14}, which was comparable to T_{11}(2.01). Therefore, under rainfed conditions, it is recommended to apply Poultry manure @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{11}) for realising higher growth and seed yield.

***Keywords*:** Growth, Integrated nutrient management, Seed yield, Soybean

Soybean (*Glycine max* L.) is an important pulse, contains 20% oil rich in vital unsaturated fatty acids and 40% good-quality protein (Layek et al 2014). With 11.13 million ha under cultivation for soybean and a production of 13.27 mt, has emerged as one of the major oilseed crops in India (FAO 2020). However, only 2.75% of the global production is contributed by India due to low productivity of 0.98 t/ha (USDA 2020). Among the factors responsible for low productivity, inadequate fertilizer use, the establishment of numerous nutritional deficits due to poor recycling of organic resources, and an imbalanced application of fertilisers are significant contributors to low production (Chaturvedi et al 2010). INM has all-around potential for the improvement of plant performance and resource efficiency while also enabling the protection of the environment and resource quality. It may consist of organic manures *viz*. poultry manure, vermicompost, vermiwash, farmyard manure and other sources for sustainable agriculture. Poultry manure enhances the physical, chemical and biological fertility of soils (McGrath et al 2009). Vermicompost has been proved effective to enhance growth and yield of soybean and other crops when used with other organic fertilizers (Javed and Panwar 2013). Vermiwash has been supplemented with elements that help plants develop well (Gorakh et al 2009). FYM plays an important role in making the nutrients available to crop. The use of biofertilizers like *Rhizobium*, PSB, VAM, KSB, and ZnSB in combination with organic manures reduces the amount of inorganic fertilizer needed, lowering cultivation costs and enhancing soil health. To improve plant growth and yield, *Trichoderma* spp. may be applied in combination with other microbial species (Rudresh et al 2005). The integrated nutrient management is the most promising concept for managing long term soil fertility and productivity (Ramesh et al 2010). In Kashmir, although soybean is cultivated as an intercrop, but not grown on a commercial scale. However, the *kharif* season in Kashmir offers a suitable choice for this crop to be grown, which can go a long way in supplementing the dietary oil and protein requirement of the valley. Thus, present study aims to explore the influence of integrated nutrient management on growth, yield and economics of soybean under rainfed conditions of Kashmir valley.

MATERIAL AND METHODS

The field experiment was carried out at Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura, Sopore, during *Kharif* 2020, located in the northern part of the Jammu and Kashmir. The treatments included, Control (T_1),

100% RD: (NPK:40:100:40) (T_2), FYM @ 10 t/ha (T_3), Vermicompost @ 2.5 t/ha (T_4), Poultry manure @ 2.5 t/ha (T_5), Vermiwash @ 10% (T_6), *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_7), 100% RDF + *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_8), *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* + Vermiwash @ 10% + 50% RDF (T_9), Vermicompost @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{10}), Poultry manure @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{11}), FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}), 75% RDF + FYM @ 5 t/ha (T_{13}) and 50% RDF + FYM @ 5 t/ha (T_{14}). The experiment was laid out in randomized complete block design (RCBD) with three replications. The soil of the experimental site was clay loam in texture, neutral in reaction with medium available nitrogen (335 kg/ha), phosphorus (15.5 kg/ha) and potassium (215 kg/ha). Weather data was obtained from a weather station set up at the experimental site during the period of May to October of 2020, indicating that the crop had experienced mean maximum and minimum temperature of 34.5 and 4.54°C, average precipitation of 12.74 mm and mean maximum and minimum relative humidity of 79.05 and 54.73% during the growth period (Fig. 1).

The seeds were sown in lines @ 80 kg/ha maintaining the row-to-row distance of 45 cm. After two weeks of sowing, the plants were thinned and gap filled to maintain a plant-to-plant distance of 10 cm. Amounts of urea, DAP and MOP were calculated and applied as per the different treatments of NPK nutrient. The crop was harvested at maturity and threshed as per schedule. The data on growth parameters (plant height, leaf area index and dry matter accumulation), yield attributes (number of pods/plant, number of seeds/pod and 100-seed weight) and yield parameters were recorded following the standard procedures. The data analysis was done using OPSTAT software package (Sheoran et al 1998).

RESULTS AND DISCUSSION

Growth parameters: The integrated use of organic along with inorganic sources of nutrients significantly influenced the growth parameters of soybean such as plant height, leaf area index and dry matter accumulation (Table 1). Plant height was significantly higher with poultry manure @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{11}) followed by vermicompost @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{10}) and FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}). The treatment T_{11} recorded significantly highest leaf area index, followed by T_{10} with no significant differences. The maximum dry matter accumulation was recorded in T_{11} followed by T_{10}, T_{12} being at par with T_{11}. It may be due to the absorption of sufficient nutrients through chemical fertilizers at initial stages of growth and later through organic sources, which may have led to more nucleic acid and amino acid synthesis, amide substances in the growing region, ultimately increasing the growth attributes in these treatments. These findings agree with earlier researchers (Jain, 2015, Sheikh et al 2015, Sutrismo, 2017).

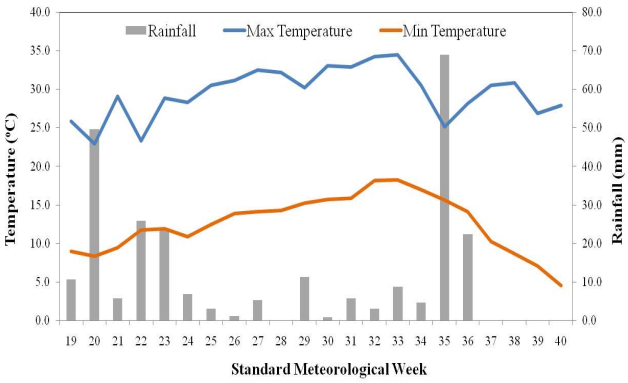

Fig. 1. Weather conditions prevailed during the crop growth period of *Kharif* 2020

Yield attributes: The amount of pods/plant in soybean was significantly influenced by the integration of different organic and inorganic sources of nutrients, however, number of seeds/pod and 100-seed weight were found to be insignificant (Table 1). The highest number of pods/ plants was recorded with poultry manure @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{11}). The treatment with vermicompost @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{10}) followed by FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}) and 100% RDF + *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_8) were at par with (T_{11}). It is possibly due to the improvement in physical and biological properties of soil and increased nutrient supply to crop, which in turn, enhanced the accumulation of carbohydrates, proteins and their translocation. Similar findings were reported by Yagoub et al (2015), Sheikh et al (2015), Nagar et al (2016) and Sutrisno (2017).

Yield: The yield of soybean was significantly influenced by the integration of different sources of nutrients in terms of seed yield, straw yield and harvest index (Table 1). The treatment with poultry manure @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{11}) recorded significantly highest seed yield. However, vermicompost @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{10}) followed by FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}) and 100% RDF + *Rhizobium* + PSB + VAM + KSB + ZnSB + *Trichoderma* (T_8) were at par with (T_{11}). Similarly, the highest stover yield was recorded in T_{11}. However, the highest harvest index was observed in the treatment with FYM @ 10 t/ha + Vermiwash @ 10% + 50% RDF (T_{12}). It may be due to slow and steady availability of nutrients during entire crop growth besides inorganic forms, which might have induced cell division,

Table 1. Growth, yield, attributes and economics of soybean influenced by different sources of nutrients

Treatments	Plant height (cm)	Leaf area index	Dry matter accumulation (g/plant)	Number of pods/plant	Number of seeds/pod	100-seed weight (g)	Grain yield (q/ha)	Straw yield (q/ha)	Harvest index (%)	Net returns (₹/ha)	Benefit-Cost ratio
T_1	104.35	1.47	33.56	45.90	2.17	18.81	9.03	23.21	27.58	24511	1.12
T_2	113.76	2.34	46.80	68.03	2.44	21.21	22.45	48.47	31.69	84393	2.79
T_3	108.85	2.04	39.57	59.09	2.70	20.89	19.95	46.16	30.12	71225	2.31
T_4	111.27	2.06	41.73	60.58	2.72	20.39	22.35	53.42	29.45	61555	1.16
T_5	113.46	2.09	43.38	58.83	2.12	20.41	22.15	48.03	31.52	77785	2.20
T_6	105.28	1.63	34.90	51.23	2.36	19.44	12.43	33.76	26.88	34988	1.21
T_7	106.71	1.84	37.18	53.38	2.42	19.32	15.75	40.10	28.62	52682	1.88
T_8	116.22	2.56	50.49	78.97	2.27	21.19	24.54	51.00	32.49	91130	2.67
T_9	114.60	2.34	45.11	68.09	2.94	21.13	22.38	51.88	30.12	75308	1.92
T_{10}	122.95	3.00	55.23	85.26	2.06	21.29	26.98	58.56	31.53	73871	1.16
T_{11}	124.78	3.16	55.97	88.65	2.09	21.32	27.35	58.75	31.76	93214	2.01
T_{12}	120.98	2.76	52.39	81.68	2.98	21.22	25.53	49.12	34.25	88149	2.10
T_{13}	119.74	2.46	48.82	73.73	2.91	20.68	23.96	50.60	32.12	87837	2.55
T_{14}	118.49	2.41	47.59	72.71	2.87	19.99	23.75	49.54	32.41	89782	2.81
CD (p=0.05)	9.75	0.24	4.98	10.32	NS	NS	3.22	7.08	3.29	16471	0.52

expansion of cell wall, meristematic activity, photosynthetic efficiency, and regulation of water intake into the cells, resulting in the enhancement of yield parameters. Highest grain and stover yield of soybean with INM were also reported by Bandopadhyay et al (2016) and Bonde and Gawande (2017). The highest harvest index with the integrated use of RDF with FYM was reported by Chaturvedi et al (2010). Similar results were reported earlier by Bachhav et al (2012), Aziz et al (2016), and Verma et al (2017).

Economics: The economics of soybean was influenced by the integration of different sources of nutrients, in terms of net returns and benefit-cost ratio (Table 1). The highest net returns (₹93,214) were with poultry manure @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{11}) while as the highest benefit-cost ratio (2.81) was with the application of 50% RDF + FYM @ 5 t/ha (T_{14}), which was comparable to T_{11} (2.01). However, with Vermicompost @ 2.5 t/ha (T_4), followed by vermicompost @ 2.5 t/ha + vermiwash @ 10% + 50% RDF (T_{10}) recorded lower benefit-cost ratio, both being 1.16. Higher values of economic returns were directly associated to higher values of grain and stover production while as the lower benefit-cost ratio could be attributed to the high cost of cultivation due to the use of vermicompost in comparison to other treatments. These results are also reported by Bachhav et al (2012), Bonde and Gawande (2017), Tomar et al (2018) and Dorota et al (2020).

CONCLUSIONS

The integration of organic and inorganic sources of nutrients influenced the growth, yield and economics of soybean. The treatment combination of poultry manure @ 2.5 t/ha along with vermiwash @ 10% and 50% RDF, proved to be the outstanding source of nutrients for the improvement of growth and yield characteristics. Similarly, the highest net returns were recorded in this treatment while as the highest benefit-cost ratio was observed in 50% RDF + FYM @ 5 t/ha, which was comparable to poultry manure @ 2.5 t/ha + vermiwash @ 10% + 50% RDF. Therefore, under rainfed conditions, it is recommended to apply Poultry manure @ 2.5 t/ha + Vermiwash @ 10% + 50% RDF (T_{11}) for realising higher growth and seed yield.

AUTHORS CONTRIBUTION

Sualiya Rashid is PG Scholar and conducted research, Amjad Masood has conceptualized the research idea, Lal Singh, assisted in soil, plant sampling and analysis S. Sheraz Mahdi has assisted in manuscript writing and final editing, Malik Asif Aziz, provided fertilizer inputs and assisted in layout plan of field experiments.

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Influence of Different Dates of Transplanting on Yield Performance and Quality of Basmati Rice Cultivars

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Abstract: The study was conducted on influence of different dates of transplanting on yield performance and quality of basmati rice cultivars at Division of Agronomy, Faculty of Agriculture, SKUAST- Jammu, Chatha during the *Kharif* season of 2022 comprising factor A as different dates of transplanting *viz*., 1st July, 10th July, 20th July and 30th July and factor B basmati rice cultivars *viz*., Basmati-370, Jammu Basmati-138, Jammu Basmati-118 and Jammu Basmati-123. The 1st July transplanted crop recorded significantly higher growth, yield attributes and yield which was statistically at par with 10th July transplanted crop. Jammu Basmati-118 performed significantly better in terms of yield attributes and grain yield which was statistically at par with Jammu Basmati-138. The significantly highest kernel length after cooking was in 1st July transplanted crop and Jammu Basmati-118. Jammu Basmati-118 and 1st July transplanting recorded significantly highest yield along with highest net returns and B:C ratio of ₹ 217476 ha^{-1} and 4.6, respectively. Henceforth, basmati rice cultivars should be transplanted from 1st to 10th of July for realizing maximum yield along with improved kernel length after cooking.

Keywords: Basmati rice cultivars, Transplanting dates, Quality, Yield performance

Rice (*Oryza sativa* L.) is a vital staple food for most of the world's population and approximately 85% of Indian population (Mohapatra, 2014). On a global scale, India ranks as the world's second largest rice producer, where it is cultivated over an area of 45 million hectares with a production and productivity of 122.27 million tonnes and 27.13 quintals $hectare^{-1}$(Anonymous 2021). In Jammu and Kashmir rice is cultivated on 267.58 thousand hectares, producing 5816 thousand quintals with an average productivity of 21.73 quintals $heactare^{-1}$ (Anonymous, 2020-21). Basmati, a premium rice has occupied an exceptional place in domestic as well global market. Globally, India ranks first in the basmati rice production with export earning of ₹ 26,416.49 crores by exporting a produce of 3,948,161.03 million tonnes during the year 2021-22 (APEDA 2022). Basmati rice is predominantly grown in the foothills of the Himalayas (Punjab, Haryana, Delhi, Uttarakhand, Himachal Pradesh, Jammu & Kashmir and Western Uttar Pradesh). The Union Territory of Jammu & Kashmir produces 1350 thousand quintals from an area of 62 thousand hectares (Anonymous 2018). Nevertheless, in recent years, there has been a notable decrease in both yield and quality of basmati rice, which could be attributed to the vulnerability of traditional cultivars to diseases, lodging, delayed maturation as well as the climate change. Optimizing transplanting dates, considering the photoperiod sensitivity, presents an agronomic cum climate-smart approach. This, coupled with specific cultivar selection, can enhance both quantitative and qualitative yield and thus food and economic security for farmers. Delay in transplanting has resulted in reduction of growth and yield (Abhilash et al 2021, Sharma et al 2022). Thus, the present investigation was undertaken with the objective to evaluate the growth, yield and quality of basmati rice cultivars along with economics under varied dates of transplanting.

MATERIAL AND METHODS

Field experiment was conducted during the during *kharif* season of 2022, at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha (32^0 40´ N latitude, 74^0 58´ E longitude). The experiment comprised of four basmati rice cultivars (Factor A) *viz*., V_1: Basmati-370, V_2: Jammu Basmati-138, V_3: Jammu Basmati-118 and V_4: Jammu Basmati-123, and four dates of transplanting (Factor B) *viz*., D_1: 1st July, D_2: 10th July, D_3: 20th July and D_4: 30th July, resulting in sixteen treatment combination, each replicated thrice within a factorial randomized block design. The soil of the experimental field was sandy clay loam in texture, slightly

alkaline in reaction, low in organic carbon (3.84 g kg^{-1}) and available nitrogen (243.10 kg ha^{-1}), and medium in available phosphorus (15.86kg ha^{-1}) and potassium (153.89 kg ha^{-1}). The recommended doses of fertilizers were applied to the basmati rice cultivar as per the package of practices provided by the SKUAST-Jammu. Full quantity of phosphorous, potash and 1/3rd of nitrogen were applied through DAP, MOP and Urea at the time of puddling and incorporated into the soil thoroughly, while remaining 2/3rd nitrogen is applied in two splits –one at 30 days after transplanting and the other at 50 days after transplanting. Growth, yield and yield of basmati rice cultivars were recorded. The total grain yield was recorded by separately weighing the cleaned grains from each net plot and converted to kg ha^{-1}. Straw yield was weighed separately from each net plot after threshing and expressed in kg ha^{-1}. The harvest index was calculated (Nichiporovich 1967).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

Kernel length after cooking was taken from ten cooked rice grains after soaking 25 whole milled rice grains in 20 ml distilled water followed by boiling water bath immersion for 12 minutes. The cooked rice was placed on a petri dish lined with filter paper before taking the reading. The data recorded was statistically analyzed using Fisher's analysis of variance technique. The software used for the data analysis were MS Excel and OPSTAT.

RESULTS AND DISCUSSION

Growth parameters: Early transplanting on 1st July resulted in significantly better plant height, dry matter accumulation and number of tillers $meter^{-2}$ at harvest compared to transplanting on 20th July and 30th , however, were statistically at par with 10th July transplanting (Table 1). This could be attributed to the fact that early transplanting provided an extended vegetative growth period due to photoperiodic response. This, in turn, might have led to a higher accumulation of photosynthates and their subsequent utilization for the growth of vegetative organs of the plant. These results were in conformity with Kumar et al (2017) and Tolma (2021). The significantly higher plant height and number of tillers $meter^{-2}$ were recorded by Jammu Basmati-123 over Jammu Basmati-118. The performance was statistically at par with Jammu Basmati-138 and Basmati-370. The dry matter accumulation at harvest in Jammu Basmati-118 was significantly higher over Basmati-370 and was statistically at par with Jammu Basmati-123 and Jammu Basmati-138. Vishwakarma et al (2016) also confirmed a variation in the growth parameters among the different rice hybrids under investigation. These differences might be attributed to the genetic makeup of the cultivars.

Yield attributes and yield: Transplanting basmati rice on 1st July significantly produced highest number of effective tillers $meter^{-2}$ and number of grains panicle over 20th and 30th July transplanted crop, but was statistically comparable to 10th July transplanting. 1000-grain weight was not affected by different transplanting dates. Significantly highest grain and straw yield was recorded under 1st July transplanting compared to 20th July and 30th July transplanting, but was statistically similar to 10th July transplanting. The increased yield related characteristics and consequently, the final yield

Table 1. Influence of different dates of transplanting on growth and yield parameters of basmati rice cultivars

Treatments	Growth parameters			Yield parameters		
	Plant height (cm)	Dry matter accumulation (g m^{-2})	Number of tillers (m^{-2})	Number of effective tillers (m^{-2})	No. of grains $panicle^{-1}$	1000-grain weight (g)
Basmati rice cultivars						
V_1(Basmati-370)	158.67	821.72	276.67	227.08	62.92	21.13
V_2 (Jammu Basmati-138)	164.26	963.14	291.67	250.00	69.13	21.51
V_3 (Jammu Basmati-118)	132.35	975.74	303.33	262.08	71.13	21.78
V_4 (Jammu Basmati-123)	164.84	970.08	306.25	245.00	66.68	21.44
CD (p=0.05)	6.62	50.35	12.42	14.44	3.49	NS
Dates of transplanting						
D_1 (1st July)	169.74	1052.13	315.42	267.50	72.24	21.83
D_2 (10th July)	163.45	1002.76	303.33	257.08	70.28	21.61
D_3 (20th July)	149.69	875.10	288.75	240.42	66.26	21.27
D_4 (30thJuly)	137.24	800.69	270.42	219.17	61.07	21.16
CD (p=0.05)	6.62	50.35	12.42	14.44	3.49	NS
Interaction (V×D)	NS	NS	NS	NS	NS	NS

Table 2. Yield, quality and economics as influenced by different dates of transplanting and basmati rice cultivars

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)	Kernel length after cooking (mm)	Net returns (₹ ha^{-1})	Benefit-cost ratio
Basmati rice cultivars						
V_1 (Basmati-370)	2876.26	5713.38	33.38	12.86	161886	3.4
V_2 (Jammu Basmati-138)	3498.74	6212.63	36.01	12.02	206140	4.3
V_3 (Jammu Basmati-118)	3646.46	6398.99	36.25	13.62	217224	4.5
V_4 (Jammu Basmati-123)	3267.68	6755.05	32.49	13.03	190861	3.9
CD (p=0.05)	249.69	400.83	1.97	0.26		
Dates of transplanting						
D_1 (1st July)	3791.67	6789.14	35.79	13.32	227710	4.7
D_2 (10th July)	3545.45	6549.24	35.09	12.98	210090	4.4
D_3 (20th July)	3184.34	6077.02	34.41	12.77	184068	3.8
D_4 (30th July)	2767.68	5664.65	32.84	12.45	154241	3.2
CD (p=0.05)	249.69	400.83	1.90	0.26	-	-
Interaction (V×D)	NS	NS	NS	NS	-	-

under early transplanting might be attributed to the fact that these yield parameters are influenced by growth and development of a plant during the vegetative phase. Better growth conditions under early transplanting likely led to improved partitioning of photosynthates from source to sink resulting in higher yield attributes and yield. These results are in agreement with the work of Limochi and Eskandari (2013). The reduction in yield under delayed transplanted might be associated with the decreased temperature during anthesis and grain filling stages of the crop (Gill et al 2006). The yield attributes and yield were significantly influenced due to basmati rice cultivars. Jammu Basmati-118 produced statistically similar number of effective tillers meter^{-2}, number of grains panicle and grain yield. However, significantly highest values were exhibited in terms of these parameters by Jammu Basmati-118 over Jammu Basmati-123 and Basmati-370. Genetic traits of this cultivar enabled the plants to convert higher energy into production of higher yield attributes and yield as highlighted in the study of Singh et al (2013). In terms of straw yield Jammu Basmati-123 produced significantly comparable straw yield with Jammu Basmati-118 but significantly higher was recorded over Jammu Basmati-138 and Basmati-370. This might be due to superior growth parameters like number of tillers meter^{-2}. These results are in accordance to the findings of Baghel et al (2013).

Harvest index was also influenced both the choice of basmati rice cultivars and the transplanting dates. Significantly higher harvest index was obtained under 1st July transplanting which remained statistically at par with 10th and 20th July transplanting. Between the cultivars Jammu Basmati-118 resulted in significantly higher harvest index over other cultivars and remained at par with Jammu Basmati-138.

Quality parameters: Kernel length after cooking is an important quality trait of basmati rice. 1st July transplanting exhibited significantly highest value for kernel length after cooking followed by 10th July, 20th July, and 30th July, respectively. These results are in line with the findings of Mahajan et al (2009) in Super basmati. Among the basmati rice cultivars, Jammu Basmati-118 recorded significantly highest value for kernel length after cooking followed by Jammu Basmati-123, Basmati-370 and Jammu Basmati-138, respectively. The genetic composition of the crop determines its characteristics resulting in variation in quality attributes (Gautam et al 2008).

Economics: The timely transplanting practice with appropriate crop cultivars does not require additional expenditure but gives acceptable yield and net returns. 1st July transplanting emerged as a more cost-effective option, giving a maximum net income of ₹ 227710 ha^{-1} and benefit-cost ratio of 4.7 than other dates (Table 2). In the category of basmati rice cultivars, Jammu Basmati-118 out performed in terms of net returns and benefit-cost ratio with the corresponding values of ₹ 217224 ha^{-1} and 4.5.

CONCLUSION

The early transplanting from 1st July to 10th July not only proved optimum for producing higher growth, yield parameters, yield and quality parameters but also fetched increased net returns and benefit-cost ratio than late transplanting (20th July to 30th July). Among the basmati rice cultivars, Jammu basmati 118 and Jammu basmati-138 were statistically similar for cultivation to get higher yield. Jammu

basmati-118 realized higher net returns and benefit-cost ratio followed by Jammu basmati-138. However, there was no observed interaction between the basmati rice cultivars and transplanting dates.

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Antibacterial and Antioxidant Potential of Essential Oil of *Eucalyptus camaldulensis* and Its Major Components

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Abstract: The present study evaluated the antibacterial and antioxidant potential of the essential oil (EO) extracted from the fresh foliage of *Eucalyptus camaldulensis* Dehnh and its major constituents. The chemical profiling of the EO revealed that it is a mixture of monoterpenes (58.85%) and sesquiterpenes (39.16%). The GC-MS analysis revealed the presence of 25 chemical compounds constituting ~98% of EO with 1,8-cineole, *β*-pinene, alloaromadendrene, and *β*-eudesmol as the main constituents. The antibacterial potential of EO and three major consituents–1,8-cineole, *α*-pinene, and *β*-pinene was assessed against four bacteria: *Escherichia coli* (MTCC 2961), *Staphylococcus aureus* (MTCC 3160), *Pseudomonas aeruginosa* (MTCC 424), and *Bacillus subtilis* (MTCC 441). The antibacterial screening revealed that all the treatments except *α-pinene* were bioactive against the studied bacterial species. EO and its major constituents exhibited free radical scavenging and antioxidant activity in a concentration-dependent manner. The highest DPPH radical scavenging was observed with *α*-pinene (~72%) and the minimum (~63%) was observed in EO at the highest concentration (800 µg ml^{-1}). EO exhibited the highest potential (~52%) for reducing ferric ion as compared to its major constituents. At the lowest concentration (100 µg ml^{-1}), the reducing activity was ~10% in 1,8-cineole, ~13% in *α*-pinene, ~15% in *β*-pinene, and ~43% in EO. The maximum $^{\cdot}OH$ scavenging activity was found in 1,8-cineole in contrast to the minimum activity in the case of *β*-pinene. TAA ranged from 10–75% at the concentration range of 100–800 µg ml^{-1} of EO or its major components. Maximum H_2O_2 scavenging activity was found in *α*-pinene (~72%), whereas the minimum activity was noticed with EO (~61%) at the highest concentration. The study concludes that EO from *E. camaldulensis* and its major constituents possess antibacterial and antioxidant activity that can be exploited for industrial and pharmaceutical applications.

Keywords: Essential oil, Oxygenated monoterpenes, Sesquiterpenes, Antibacterial activity, Antioxidant potential

The traditional system of medicine since time immemorial is based on the usage of natural products originating from plants (Chaves et al 2018). Higher plants are a treasure of variety of phytochemicals that can combat the major fatal diseases (Dhakad et al 2018, Gwinn 2018). With the rapid increase in number of diseases and the growing interest in natural remedies as a cure, the extracts from different parts of medicinally important flora are widely being researched for their various bioactivities including the anticancer and antioxidant properties (Ashraf et al 2015, Ashrafi et al 2020). The natural compounds including the oils find their usage extensively in diverse sectors such as food and fragrance industry, aromatherapy, cosmetics, medicines, and agrochemicals. (Bakkali et al 2008, Pavela and Benelli 2016, Isman 2020, Irshad et al 2020) and are in much demand worldwide owing to their importance in medicines (Blowman et al 2018, Gwin 2018). The plant family Myrtaceae is the ninth largest among the flowering plant families, and includes trees and shrubs found growing abundantly in wet tropics, especially South America, Australia, and Tropical Asia (Casceas et al 2015). *Eucalyptus* is one of the largest genera of family Myrtaceae, which includes about 900 species and subspecies (Brooker and Kleinig 2006). Among the different *Eucalyptus* species, *E. camaldulensis* Dehnh. (formerly *E. rostrata* Schl.) . *E. camaldulensis* possesses EO in its various parts like leaves, buds, and fruits. EOs have been traditionally used in everyday life owing to their antiseptic, anti-inflammatory, and antipyretic properties. Despite their valuable relevance for the human consumption, there is a paucity of information on their usage relating to the pharmacological arena. The current study aimed at evaluating the chemical composition and determining Antibacterial and Antioxidant potential of the leaf essential oil of *Eucalyptus camaldulensis* and its major components.

MATERIAL AND METHODS

Plant material: The plant material, i.e. the leaves of *E. camaldulensis* Dehnh. were collected from the trees growing in the sector 14 campus of Panjab University, Chandigarh (30º45'34º N 76º45'59º E), India. The voucher specimen (PAN 21999) of the plant material was deposited in the Herbarium of the Botany department, Panjab University, Chandigarh, India.

Extraction of EOL: The freshly chopped leaves of *E. camaldulensis* were used for extraction of EO by the method of hydro-distillation using Clevenger's apparatus. About one

kg of plant leaves and 5L of distilled water were put in a round-bottom flask fitted with a condenser. After boiling the contents for about 4h, a pale-yellow aromatic, volatile oil was collected through the nozzle of the condenser. The oil obtained was dried over anhydrous sodium sulphate and refrigerated at 4ºC for its chemical profiling and the study of various bioactivities. The process of extraction of EO was repeated 3-4 times during the research work.

GC-MS: The chemical profiling of EO was determined through GC-MS (Gas chromatography-Mass spectrometry) analysis. GC was done on Shimadzu QP 2010 gas chromatograph equipped with a Flame Ionization Detector (FID) fitted with a ZB-5 column (30 m × 0.25 mm × 0.25 µm in length, diameter and thickness, respectively). Helium gas was used as a carrier gas with a flow rate of 1.05 ml min^{-1}. The split ratio was 1:10. The temperature of injector and ion source were fixed at 270°C. The ionization energy of mass spectra was 70 eV. The oven temperature was initially 100°C which was held isothermally for 2 min then increased to 200°C at the rate of 6 °C per min and finally held at 230°C for 19 min.

Chemical profiling of the oil: The relative percentage of different constituents was calculated automatically from the peak of total ion chromatograms. Constituents of the oil were identified by comparing their retention indices relative to a homologous *n*-alkane (C_9-C_{21}) series and matching their mass spectra with those of reference compounds in Wiley 275 and NBS 75 K libraries (Adams 2007).

Anti-bacterial activity: Antibacterial activity was assayed against four bacteria, *Escherichia coli* (MTCC 2961), *Staphylococcus aureus* (MTCC 3160), *Pseudomonas aeroginosa* (MTCC 424), and *Bacillus subtilis* (MTCC 441) using disk diffusion method. Each 1% nutrient agar plate was inoculated with 100 µl of 10^4 cfu ml^{-1} bacterial culture. To each sterile disk, 20 µl of sample was loaded. Antibiotic disk of norfloxacin of concentration 10 mcg $disc^{-1}$ was used as positive control. These plates were then incubated for 24 h at 37°C. After 24 h of incubation, the antibacterial activity of test samples was observed by measuring the zone of inhibition and noted to calculate the minimum inhibitory concentration (MIC) of the test samples. MIC was determined by sub-culture (as described above) as the lowest concentration resulting in the reduction in the number of organisms in inoculums. The tests were repeated at least three times and modal MIC values were selected.

Antioxidant and free radical scavenging activity: The antioxidant activity of EO was estimated by dissolving EO in methanol or acetone. Four different oil concentrations of EO were prepared, 100, 200, 400 and 800 µg ml^{-1}.

Total antioxidant activity (TAA): The evaluation of TAA of EO was done by using phosphomolybdenum method according to Prieto et al (1999).

Ferric ion reducing antioxidant power (FRAP): The FRAP activity of EO was evaluated following the method of Oyaizu (1986).

Hydrogen peroxide (H_2O_2) scavenging activity: Hydrogen peroxide scavenging activity of EO was evaluated as per the method of Ruch et al (1989).

Hydroxyl (OH) radical scavenging activity: The hydroxyl radical scavenging activity of EO was evaluated based on Fenton reaction as described by Yu *et al.* (2004) with slight modification.

DPPH (2, 2-diphenyl-l-picryl hydrazyl) radical scavenging activity: It was determined in terms of radical scavenging or hydrogen donating ability by measuring the scavenging activity against DPPH radical as per Blois et al (1958).

RESULTS AND DISCUSSION

GC-MS analysis of EO: GC-MS analysis revealed the presence of 25 chemical constituents, contributing ~98% of the total oil composition (Table 1). The main constituents identified in the oil were 1,8-cineole, *β*-pinene and *α*-pinene, analysis corresponding to their retention times (RT) of 7.88, 6.32, and 5.19 min, respectively The oil was a mixture of monoterpenes and sesquiterpenes, however, the relative percentage of monoterpenes was slightly higher. Among the monoterpenes, the fraction of hydrocarbons (36.38%) was more than the oxygenated ones (22.47%). The total percentage of the monoterpenes in the oil was 58.85% whereas sesquiterpenes constituted 39.16% of EO. As for the sesquiterpenes, its hydrocarbons accounted for 19.09% and the oxygenated sesquiterpenes were 20.07% (Fig. 1). Most abundant constituent of the oil was 1,8-cineole, an oxygenated monoterpene (17.14%) followed by *β*-pinene, a monoterpene hydrocarbon (16.48%), and aromadendrene, a sesquiterpene hydrocarbon (11.32%). In addition, significant quantities of *β*-eudesmol (10.85%), limonene (9.51%), and *α*-pinene (7.96%) were also present in the leaf oil of *E. camaldulensis.*

Antibacterial potential: Antibacterial screening of EO and its major components - 1,8-cineole, *α*-pinene, and *β*-pinene revealed that all the treatments except *α*-pinene were bioactive against the studied bacterial species (Table 2). MIC values of EO and its constituents varied from 9-27 mg ml^{-1} for each bacterial species. *S. aureus* and *P. aeruginosa* were most susceptible to 1,8-cineole and EO at MIC of 9.0 and 9.2 mg ml^{-1}, respectively . Similarly, *B. subtilis* was susceptible to 9.0 mg ml^{-1} of 1,8-cineole. One of the most resistant species was *E. coli* with MIC ranging from 17–27 mg ml^{-1} EO or its

major components. The inhibition zones of all the treatments were >10 mm, with the largest inhibition effect exhibited by 1,8-cineole for *P. aeruginosa* (Table 3). The smallest inhibition diameter was observed for *β*-pinene in *E. coli*. It was concluded that 1,8-cineole was the most effective antimicrobial agent found in EO.

Table 1. Chemical profiling of *E. camaldulensis* EO by GC-MS analysis

Constituent	RT[b]	RI_{cal}[c]	RI_{lit}[d]	Percentage
Monoterpene hydrocarbons (36.38%)				
α-Pinene	5.197	929.23	931	7.96
β-Pinene	6.325	973.21	975	16.48
β-Myrcene	6.541	980.73	978	0.96
p-Cymene	7.639	1018.20	1023	1.47
Limonene	7.798	1023.63	1025	9.51
Oxygenated monoterpenes				
1,8-Cineole	7.889	1026.68	1031	17.14
β-Citronellal	12.842	1170.71	1167	0.35
4-Terpineol	12.914	1172.60	1177	1.02
α-Terpineol	13.437	1186.03	1189	3.96
Sesquiterpene hydrocarbons				
α-Copaene	19.732	1364.10	1372	0.60
α-Gurjunene	20.807	1393.66	1402	0.61
trans-Caryophyllene	21.221	1405.72	1415	1.88
Calarene	21.59	1417.57	1423	0.49
Aromadendrene	21.865	1426.26	1436	11.32
Patchoulene	22.077	1432.89	1459	0.38
Alloaromadendrene	22.558	1447.70	1460	2.41
α-Amorphene	23.499	1475.78	1481	0.89
α-Muurolene	23.575	1478.00	1500	0.51
Oxygenated sesquiterpenes				
Isoaromadendrene epoxide	26.451	1568.77	1579	0.42
Globulol	26.59	1573.11	1575	4.71
Viridiflorol	26.851	1581.20	1584	1.12
α-Eudesmol	27.742	1609.67	1618	0.44
di-*epi*--1,10-Cubenol	27.97	1617.64	1623	3.37
β-Eudesmol	28.687	1642.29	1645	10.85
Epiglobulol	25.84	1549.43	1564	1.16
Total oil percentage		98.01%		

Antioxidant potential: EO obtained from the leaves of *E. camaldulensis* was assessed for its radical scavenging and antioxidant potential along with its major components -1,8-cineole, *α*-pinene, and *β*-pinene against 1,1-diphenyl-2-picrylhydrazyl (DPPH) and hydroxyl radicals, hydrogen peroxide, and for total antioxidant activity and ferric ion reducing activity

DPPH scavenging potential: Gradual increase in DPPH scavenging activity with increase in the concentration of EO and its major components (Fig. 2). At the lowest concentration (100 µg ml^{-1}), the scavenging activity of EO and its constituents ranged between 20.5–48.1%. Maximum % scavenging activity (~72%) was noticed in case of *α*-pinene at highest concentration of 800 µg ml^{-1} which was significantly higher than that of EO (~63%) at the same concentration. The scavenging activities of *β*-pinene and 1,8-cineole were comparable with *α*-pinene, however, were significantly more than EO at 800 µg ml^{-1} (Fig. 2). In general, the DPPH scavenging activity was in the order - *α*-pinene > *β*-pinene > 1,8-cineole > EO. Different alphabets over the bars represent significant difference among the various treatments (EO and its constituents) at a particular concentration applying post hoc Tukey's test ($p \leq 0.05$).

Ferric ion reducing antioxidant power (FRAP) activity: EO and its components showed an increasing trend in the FRAP activity with increase in concentration of EO or its major components. In general, EO exhibited the highest (significant at $p \leq 0.05$) potential (~52%) for reducing ferric ion as compared to its other components (Fig. 3). On the other hand, at the lowest concentration (100 µg ml^{-1}), the reducing activity was around 10% in 1,8-cineole, 13% in *α*-pinene, 15% in *β*-pinene, and 43% in EO. The activity of EO was significantly more ($p \leq 0.05$) than its other constituents.

Values presented as means ± standard error. Different alphabets over the bars represent significant difference among the various treatments (EO and its constituents) at a particular concentration applying *post hoc* Tukey's test ($p \leq 0.05$).

Total antioxidant activity (TAA): TAA significantly increased with the increase in EO concentration or its major

Table 2. Minimum inhibitory concentration (MIC) of *E. camaldulensis* EO and its major constituents on the selected bacterial strains

Bacteria	EO (mg ml^{-1})	1,8-cineole (mg ml^{-1})	*α*-Pinene (mg ml^{-1})	*β-Pinene* (mg ml^{-1})
Staphylococcus aureus	$9.2 \times 10^{-3} \pm 0.00021$	$9.0 \times 10^{-3} \pm 0.0012$	–	$1.78 \times 10^{-2} \pm 0.00074$
Bacillus subtilis	$18.4 \times 10^{-3} \pm 0.00021$	$9.0 \times 10^{-3} \pm 0.0018$	–	$1.75 \times 10^{-2} \pm 0.00028$
Escherichia coli	$1.7 \times 10^{-2} \pm 0.00169$	$1.8 \times 10^{-2} \pm 0.0016$	–	$2.7 \times 10^{-2} \pm 0.00163$
Pseudomonas aeruginosa	$9.2 \times 10^{-3} \pm 0.00024$	$9.0 \times 10^{-3} \pm 0.0009$	–	$1.74 \times 10^{-2} \pm 0.00020$

components (100–800 µg ml^{-1}) and ranged from 10–75% (Fig. 3). The maximum antioxidant potential was observed in 1,8-cineole (~75%) at the highest concentration of 800 µg ml^{-1}, which was significantly ($p \leq 0.05$) more than the other constituents and EO. This was followed by EO with ~72% activity, *α*-pinene with ~63% activity, and *β*-pinene showing ~60% activity. At the minimum concentration (100 µg ml^{-1}), TAA was around 10% in EO followed by 26% in 1,8-cineole, 36% in *α*-pinene, and 38% in *β*-pinene.Different alphabets over the bars represent significant difference among the various treatments (EO and its constituents) at a particular concentration applying *post hoc* Tukey's test ($p \leq 0.05$).

Hydroxyl radical (OH) scavenging activity: In general, OH scavenging activity ranged from ~23% to ~73% at concentrations ranging from 100 to 800 µg ml^{-1} (Fig. 4). With increase in the concentration of EO and its constituents, the activity also showed an increasing trend. The maximum OH scavenging activity was measured in 1,8-cineole and noticed

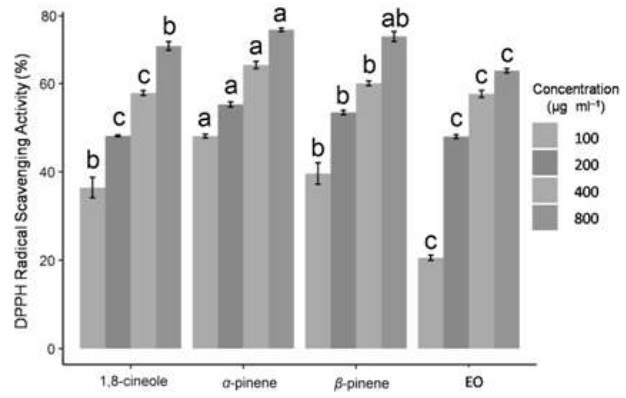

Fig. 1. DPPH radical scavenging activity of *E. camaldulensis* EO and its major constituents(mean ± standard error)

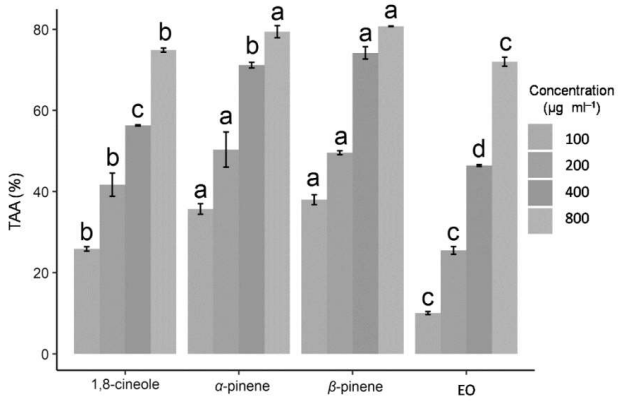

Fig. 3. Total antioxidant activity (TAA) of *E. camaldulensis* EO and its major constituents. (Mean ± standard error)

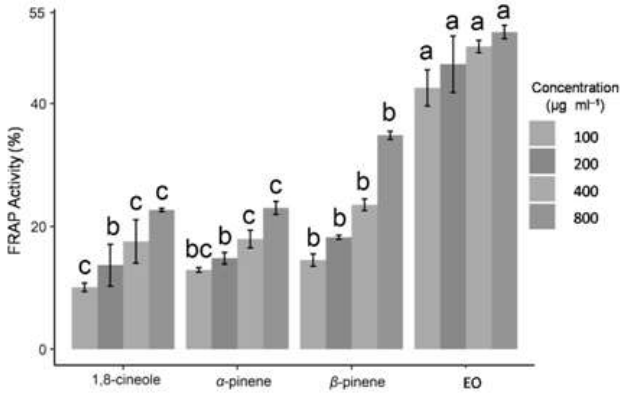

Fig. 2. Ferric ion reducing antioxidant power (FRAP) activity of *E. camaldulensis* EO and its major constituents. Data presented as mean ± standard error

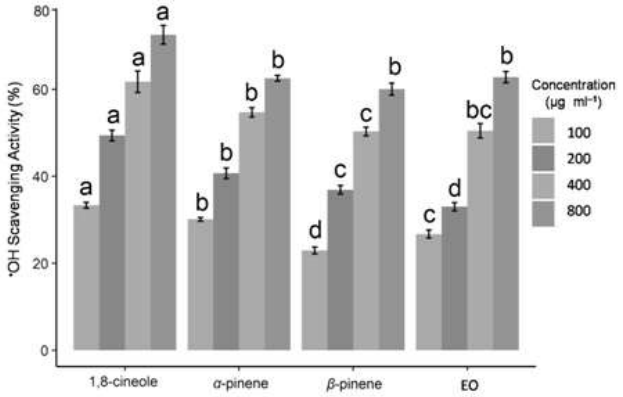

Fig. 4. Hydroxyl radical (OH) scavenging activity of *E. camaldulensis* EO and its major constituents (Mean ± standard error)

Table 3. Zone of inhibition (in mm) at minimum inhibitory concentration of *E. camaldulensis* EO and its major constituents on the selected bacterial strains

Bacteria	Zone of inhibition (mm)*				
	Norfloxacin (10 mcg/disc)	1,8-cineole	EO	*α*-Pinene	*β*-P*inene*
Bacillus subtilis	26	11.3 ± 1.24	10.6 ± 0.94	0	12.6 ± 2.05
Staphylococcus aureus	23	9.3 ± 0.94	9.0 ± 1.41	0	0
Escherichia coli	21	18.6 ± 0.94	15.3 ± 1.24	0	10.0 ± 1.63
Pseudomonas aeruginosa	22	19.3 ± 1.88	14.0 ± 1.63	0	14.0 ± 0.81

* values presented as mean ± standard error

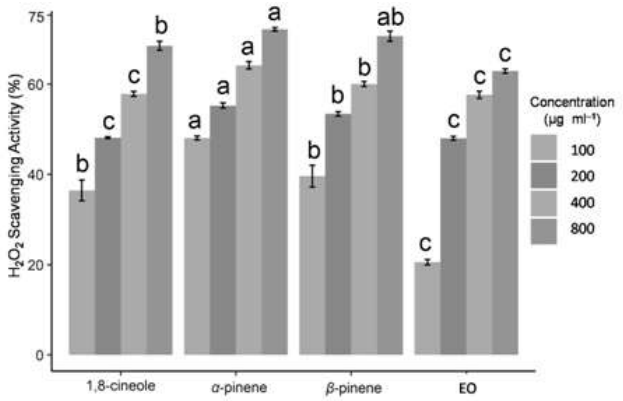

Fig. 5. Hydrogen peroxide (H_2O_2) scavenging activity of *E. camaldulensis* EO and its major constituents (Mean ± standard error)

to be ~73%, which was significantly ($p \leq 0.05$) more than EO and other constituents . At the minimum concentration (100 µg ml^{-1}), the OH scavenging activity was found to be lowest in *β*-pinene (~23%) followed by EO (~27%), *α*-pinene (~30%), and 1,8-cineole (~33%). Different alphabets over the bars represent significant difference among the various treatments (EO and its constituents) at a particular concentration applying *post hoc* Tukey's test ($p \leq 0.05$).

Hydrogen peroxide (H_2O_2) scavenging activity: Hydrogen peroxide scavenging activity of EO and its major components - 1,8-cineole, *α*-pinene, and *β*-pinene increased in a concentration-dependent manner (Fig. 5). The activity ranged from ~21 to ~48% at the minimum concentration (100 µg ml^{-1}) and ~61% to ~72% at the highest concentration, i.e. 800 µg ml^{-1}. The maximum scavenging activity was in *α*-pinene (~72%) at the highest concentration of 800 µg ml^{-1}. This was significantly more ($p \leq 0.05$)) . Different alphabets over the bars represent significant difference among the various treatments (EO and its constituents) at a particular concentration applying *post hoc* Tukey's test ($p \leq 0.05$).

CONCLUSION

Based on GC-MS, a total of 25 components were identified in EO which constituted ~98% of the oil. On the whole, the major compounds identified in EO were 1,8-cineole, *β*-pinene, alloaromadendrene, *β*-eudesmol, and *α*-pinene. Antibacterial efficacy of the oil and its constituents was also explored, and it was found to be maximum in 1,8-cineole. Further, the inhibition was most pronounced in the gram-negative bacteria, *Pseudomonas aeruginosa.* EO and its major constituents also exhibited free radical scavenging as well as antioxidant activity. *α*-Pinene showed maximum scavenging activity for DPPH radical, whereas EO showed the minimum activity. EO exhibited highest potential for reducing ferric ion compared to its major constituents. In case of OH radical**,** the scavenging activity was observed to be maximum in 1,8-cineole, whereas it was least in *β*-pinene.

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Effect of Nanoparticles in Development of Novel Protocol for Micropropagation of *Pterocarps santalinus* L.

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Abstract: *Pterocarpus santalinus* L. a medicinal and highly commercial timber yielding tree taxon of Fabaceae and is endemic to deccan region and included in critically endangered plant list. Number of attempts had been carried out by researchers to develop protocol for *in vitro* propagation of this plant for production of plants, as the seeds have dormancy. In the current attempt, nanoparticle mediated/included medium was developed for multiple shoot production from explants and also identification of suitable sterilization techniques to nullify the effects of secondary metabolites extruded from explants in to the medium used for micro propagation of *Pterocarpus santalinus*. Axillary buds were selected after screening several explants like nodal segments, shoot tips and leaves based on the response of shoot initiation. MS medium better than Woody plant and B5 media. Surface sterilization of explant with various concentrations and time initials of ascorbic acid PVP and $HgCl_2$ 35% of $HgCl_2$ at 3 min was best among the tested chemicals to remove microbial contamination. Maximum number of secondary metabolites were extracted with methanol than aqueous, acetone, chloroform and diethyl ether from axillary buds to synthesize the nanoparticles.

Keywords: *Pterocarpus santalinus,* Mcropropagation, Nanoparticles

Silver nanoparticles (AgNPs) are one of the most widely fascinating area and applicable particles whose application is enhanced in the nano world circadian. There is growing awareness in correlating the phytochemical constituents of a medicinal plant with its pharmacological activity. A red sander has fallen back into the endangered category in the IUCN Red list-2022. The seeds of *Pterocarpus santalinus* possess dormancy due to its hard seed coat. Moreover the growth is also slow. Hence in vitro cultivation is one of the methods to propagate. Number of authors tried with embryonic axis, cotyledons and leaves (Rajeswari and Paliwal 2008, Padmalatha and Prasad 2008). The explants oozed out phenols into the medium is another obstacle for micropropagation of *P. santalinus*. Hence sterilization and removal of secondary metabolites from explants is the prime step for *in vitro* propagation. In the present study an attempt has been made to *in vitro* propagation of *P. santalinus* with AgNP after removing the secondary metabolites from explant.

MATERIAL AND METHODS

Selection of candidate plus trees: Candidate plus tree was selected in the natural population of Seshachalam hills based on girth of the trunk and collected explants for experimentation.

Collection of explants: Healthy shoot tips and axillary buds of red sanders were collected from the tree. Axillary buds were washed thoroughly under running tap water for 30 min and then with 5% teepol for 8-10 min and rinsed 2-3 times in sterile distilled water. Then explant was treated with 1% carbendazim to avoid microbial contamination after that washed 2-3 times to remove the traces of carbendazim and washed with distilled water. Thereafter, the explant was pre-soaked with 1% ascorbic acid for 2-6 min followed by 1% PVP for 2-6 min and surface sterilized with 0.1% $HgCl_2$ solution for 0- 5 min followed by thorough washing with sterile distilled water. The sterilized explants were inoculated on MS medium supplemented with various concentrations of activated charcoal for shoot initiation. The pH of the media was adjusted between 5.6 and 5.8 before autoclaving at 15 lbs. /cm^2 at 121°C for 20 min. Cultures were incubated at 25 ± 2 C and 65 - 70% relative humidity with a photoperiod of 16/8 h at 3000 lux intensity by fluorescent tubes.

Phytochemical analysis: Explants were collected and carried out qualitative analysis of secondary metabolites.

Preliminary Phytochemical Screening: The above obtained Soxhlet extracts were used for preliminary phytochemical testing nearly 13 components namely flavonoids, steroids, tannins, glycosides, saponins, alkaloids, phenols, anthraquinones, anthocyanins, coumarins, lignins, proteins and triterpenoids was done by the standard procedures (Harborne 1984 , Kokate et al 1991).

Synthesis and characterization of nanoparticles: Five ml of aqueous bark extract were taken into 250 ml conical flask and titrated with 50 ml of silver nitrate with heating between 60-80oC for 60 min. Color change from light brown to deep brown indicated formations of silver nanoparticles. Then were centrifuged at 20000 rpm for 20 min to remove the presence of biological admixture, and were used for characterization and as well as antibacterial, antioxidant activities.

Characterization: UV-Vis absorption spectrum of SNPs was used with nanodrop 800 nm spectrophotometer. Fourier Transform Infra-Red (FT-IR) spectra of synthesized SNPs were analyzed in the range of 4000 to 500 cm1 with an ALPHA interferometer (ECO-ART), Bruker, Ettlingen, Karlsruhe, Germany by KBr pellet method. Crystalline nature of metallic silver nanoparticles were monitored using an X-ray diffract meter (XRD) from Shimadzu, XRD-6000 equipped with Cu Ka radiation source using Ni as filter at a setting of 30 kV/30 mA. Scanning electron microscopy (SEM) and percentage of silver ions in synthesized samples was done by using FEI Quanta 200 FEG HR-SEM machine equipped with EDAX instrument. Transmission electron microscopy (TEM) analysis was performed with the using HF-3300 advanced 300 kV TEM from Hitachi.

RESULTS AND DISCUSSION

The axillary buds from candidate plus tree were treated with 1% ascorbic acid for 2-6 min followed by in PVP at different time intervals of 2-8 min and then the sterilant HgCl2 0.1% was treated during the surface sterilization at different time intervals of 0-4 min. They have shown 100% infection free explants at the time interval of 4 min with 1% ascorbic acid followed by 1% of PVP at 6 min and 0.1% HgCl2 for 3min of duration with 90% of response. Therefore, the axillary buds were selected for micro propagation. The explants at 4 min of 0.1% HgCl2 is showing 83% of infection free plants but the response is only 50%.

Mercuric chloride (HgCl2) is stronger than sodium hypochlorite (NaClO), which is the likely reason for its effectiveness in combating fungi, bacteria and endogenous microbial species (MngOmba et al 2012). The effect of 0.1% $HgCl_2$ surface sterilization on *in-vitro* propagation of *P. santlinus*, to overcome the problem of fungal and bacterial contamination.

There are huge variations regarding tissue culture response in explants excised from plants grown in field conditions depending on weather conditions. The mortality of the cultures may be higher due to damage caused by stronger disinfectants, as reported from *Calophylulum apetalum* (Nair and Seeni 2003).

Aqueous extract showed the presence of flavonoids, glycosides, saponins, alkaloids, phenols, coumarins and lignins followed by Acetone and diethyl ether extracts showed the presence of steroids, glycosides, saponins, alkaloids and phenols. In chloroform and diethyl ether extracts only flavonoids, glycosides, saponins, phenols and steroids were present. Among all the solvents, methanol is the best suitable solvent for extracting *P. santalinus* bioactive compounds. Similar results were observed in *Boswellia ovalifoliolata*, *Shorea tumbuggaia, Cochlospermum religiosum, Syzygium alternifolium, Terminalia pallida*. The quantitative estimation of secondary metabolites of *P. santalinus* axillary buds were rich in alkaloids, flavonoids, phenols, saponins, tannins, proteins and carbohydrates. Highest number of alkaloids 0.617 mg/g d.wt are present in the shoot tip. Alkaloids are beneficial chemicals to plants with predators and parasite repelling and physical state. Number alkaloids are isolated from dicots and using efficient drugs. The alkaloids are one of the most diverse groups of secondary metabolites found in living organisms and have an array of structure types, biosynthetic pathways and pharmacological activities. The presence of alkaloids contained in plants are used in medicine as aesthetic agents. Axillary buds are rich in phenols 1.893 mg/g dw and flavonoid 1.713 mg/g dw. When the 1 mM Ag(NO3)2 solution was added to aqueous axillary buds extract of *P. santalinus*, the color changed from light brown to deep brown which is the primary method to confirm that the synthesized nanoparticles are silver (Fig.1). The color change is because of the reduction of silver ions with the help of bio active molecules

Table 1. Standardization of surface sterilization of axillary buds as explants of *Pterocarpus santalinus*

Treatment duration (min)			Number of explants (%)		Number of explants responded (%)	Mortality (%)
$HgCl_2$0 (1%)	Ascorbic acid (1%)	PVP (1%)	Infection free	With Infection		
0	0	0	25.00	75.00	25.00	0.00
1	0	2	58.33	41.67	50.00	8.33
2	2	4	66.67	33.33	50.00	16.67
3	4	6	100.0	00.00	91.67	8.33
4	6	8	83.33	16.67	50.00	33.33

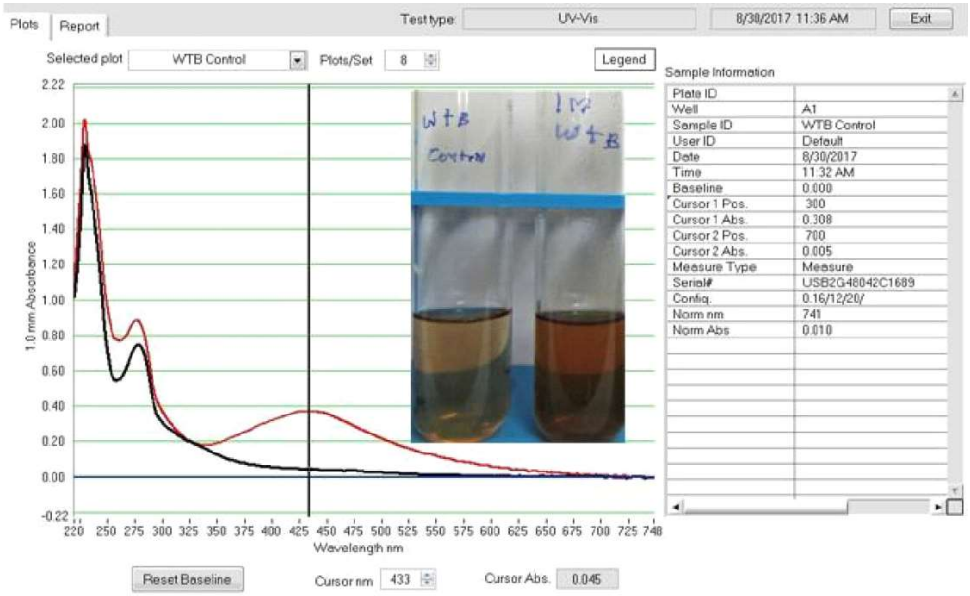
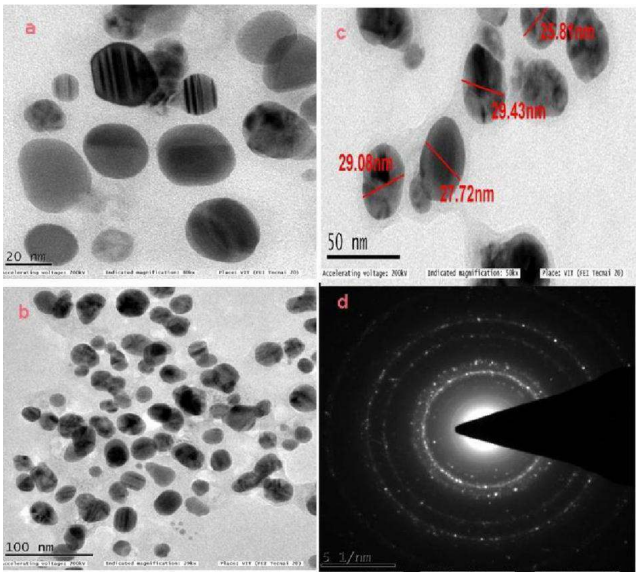


Fig. 1. Visible colour change of SNPs with UV Visible absorbance peak at 433 nm



a) Spherical shape of SNPs at 20 nm
b) Dispersion of the nanoparticles at 100 nm
c) Average size of AgNPs at 50 nm 28.01nm
d) Imaging at 51 nm

Fig. 2. TEM Images of synthesized nanoparticles

Control AgNP treated

Fig. 3. Growth of axillary buds on MS medium supplemented with silver nanoparticles

present in the sample. NAD and ascorbic acid present in plant parts at higher levels act as strong reducing agents by donating electrons to Ag^{+} to form Ag^{0} nanoparticles. This may be the main reason behind the reduction and color change pattern of silver nanoparticles.

TEM: Morphological structure and distribution of synthesized silver nanoparticles monitored at high magnifications (20nm) were done by TEM. TEM micrographs show that the synthesized nanoparticles are poly dispersed, predominantly spherical in shape, owing 25.81-29.43 nm size and no physical contact with each other i.e. no agglomeration of nanoparticles were seen. For TEM analysis the SNPs are coated on copper grids and analyzed by Hitachi HF3300 advanced with 300kV (Fig. 2). AgNPs due to its nano size enter into the tissue and allow the nutrients to utilize optimum level by growing tissue; hence the shoot growth is enhanced in AgNP treated medium when compared to that of control (Fig. 3). The initial finding of the present study paves the way to further research to find out fast growth of shoots and roots in micropropagation of woody plants.

Table 2. Standardization of activated charcoal on axillary buds as explants from *Pterocarpus santalinus*

Sterilant used	Number of explants (%)		Number of explants responded (%)	Mortality (%)
Activated charcoal used in blank MS medium(100ml)	Infection free	With Infection		
0.1 gm	0	100	0.00	0
0.5 gm	8.33	91.67	0.00	8.33
1.0 gm	25.00	75.00	16.66	8.33
1.5 gm	66.67	33.33	33.33	33.33
2.0 gm	83.33	16.67	66.67	16.66

Table 3. Qualitative analysis of bio metabolites from axillary buds of *P. santalinus*

Tests	Aqueous	Acetone	Chloroform	Diethyl ether	Methanol
Flavonoids	+	-	+	+	+
Steroids	-	+	-	+	+
Tannins	-	-	-	-	+
Saponins	+	+	-	+	+
Alkaloids	+	+	-	-	+
Phenols	+	+	-	+	+
Triterpenoids	-	-	-	-	+
Anthraquinones	-	-	-	+	+
Anthocyanins	-	-	-	-	+
Coumarins	+	-	-	-	-
Lignins	+	-	-	-	+
Proteins	-	-	-	-	-
Glycosides	+	+	+	-	+
Total	07	05	02	05	11

+ indicate presence & - indicates absence

Table 4. Quantitative analysis of bio metabolites from different parts of *P. santalinus*

Phytochemicals	Quantity mg/g D.W.
Alkaloids	0.114±0.088
Flavonoids	0.333±0.088
Phenols	0.371±0.057
saponins	0.362±0.088
Tannins	0.052±0.057
proteins	0.212±0.021
Carbohydrates	0.075±0.057

Values are average ±, SE

CONCLUSION

The present study concluded that axillary bud is the best explant for micropropagation of *Pterocarpus santalinus* and for effective disinfection optimum concentration of 0.1% $HgCl_2$ for surface sterilization of explant. The presence of high phenols, flavonoids, tannins and alkaloids exudation from explant into culture medium affects the growth of shoot induction. Silver nanoparticles in the medium reverse the effect of secondary metabolites in the MS culture medium for *in vitro* propagation of *Pterocarpus santalinus.*

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Finger Millet System Productivity as Influenced by Liquid Biofertilizer Consortium

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***Abstract*:** Field experiment was conducted at University of Agricultural Sciences, Bangalore to study the significance of liquid bio fertilizer consortium and modes of its application on growth, yield and nutrient uptake by crop and soil fertility of transplanted finger millet. The treatments included 100, 85 and 70 per cent of recommended dose of fertilizers with liquid bio fertilizer consortium through different methods of application *viz.,* seed treatment, soil application and seedling root dip. Application of 100 per cent RDF + combined methods of application with liquid bio fertilizer consortium (seed treatment, soil application and seedling root dip) numbered as the best technology by having obtained having higher plant height at harvest(102.9 cm), tillers per plant (4.2), dry matter accumulation at harvest (52.12 g/plant), grain and straw yield (4080 and 7810 kg/ha, respectively), nutrient uptake (76.57, 36.40 and 76.53 kg nitrogen, phosphorous and potassium/ha, respectively) with slightly higher post-harvest available nutrients in soil (244, 86 and 210 kg N, P_2O_5 and K_2O/ha, respectively) and higher soil microbial count at 50% flowering (52.3 , 38.6 cfu/g× 10^6 and 16.6 cfu/g× 10^3 bacteria, fungi and actinomycetes, respectively). However, this treatment par with 100% RDF + soil application for all the parameters and emerged as most feasible treatment from the perspective of higher profitability and practical feasibility.

***Keywords*:** Finger millet, Liquid bio fertilizer, Consortium, Application, Yield, Microbes, Nutrients

The agriculture sector is considered as one of the economy pillars in many developing nations. However, continuous use of agrochemicals such as chemical fertilizers and pesticides in this sector is detrimental to fertility status of soil. The frequent usage of chemical fertilizer will also cause soil compaction which negatively affects the crop roots, making them unable to acquire nutrients. Damage caused by chemical fertilizers is often long-term and cumulative, hence there is need to consider alternative and sustainable methods and soil application of liquid bio fertilizer can play vital role. Application of liquid bio fertilizer consortium along with inorganic fertilizers have received a considerable amount of attention as the microbes in consortium are effective in promoting plant growth by secreting phyto hormones, metabolites and plays vital role in enhancing yield, uptake of nutrients by crop and fertility status of soil. Liquid bio fertilizer consortium contains *Azospirillum lipoferum* (nitrogen fixer), *Bacillus megaterium* (phosphorous solubilising bacteria) and *Frateuria aurantia* (potassium solubilising bacteria). *Azospirillum* enhance non-legume plant growth by directly affecting plant metabolism. Phosphorus is abundant in soil but present in complex unavailable forms hence it is exploited by application of phosphate solubilising microbes. The potassium is made available to plants when the minerals are slowly solubilised by potassium solubilising microbes. In India, Finger millet is grown in an area of 12.18 lakh ha with a production of 17.10 lakh tons and a productivity of 1396 kg ha^{-1}. Karnataka is the largest producer of finger millet in India and grown in 8.46 lakh ha with an annual output of 11.26 lakh tons and a productivity of 1332 kg ha^{-1} (Indostat 2022). Because of continuous cropping, inadequate crop residue recycling, and low rates of organic matter application, most soils in semi-arid tropics where finger millet is grown are deficient in macro and micronutrients, which can limit its yield potential (Rao et al 2012 and Sukanya et al 2022, 2023). The integrated nutrient management is an important approach for increasing productivity. Despite the fact that farmers regard finger millet as a low-fertilizer demanding crop, but crop also responds well to fertilizer application Rurinda et al (2014) and Lavanya et al *(*2018). Thus, the present investigation is carried out to assess effect of liquid bio fertilizer consortium on growth, yield, nutrient uptake and fertility status of soil.

MATERIAL AND METHODS

Field experiment on Effect of liquid bio fertilizer consortium on growth, yield, nutrient uptake and soil fertility of transplanted finger millet was conducted during summer 2020 and 2021 at Zonal Agriculture Research Station (ZARS), University of Agricultural Sciences, GKVK, and

Bangalore. Experimental site had red sandy loam, slightly acidic pH, low organic carbon content (0.34%), low available nitrogen (225.9 kg/ha), high phosphorus (66.3 kg/ha) and medium potassium (199.6 kg/ha). The experimental location comes under semi-arid tropical climatic condition, 924 metre above mean sea level, minimum temperature 18.2^{0}C and maximum temperature 29.8^{0}C, minimum relative humidity 50.7% and maximum relative humidity 87.4%, and receives a normal rainfall of 920 mm and the location is falling under Eastern dry zone of Karnataka. Randomized complete block design was adopted in the experiment with three replications. Liquid biofertilizer consortium contained *Azopirillum lipoferum* (nitrogen fixer), *Bacillus megaterium* (phosphorous solubilising bacteria) and *Frateuria aurantia* (potassium solubilizing bacteria) which were procured from the Department of Microbiology, College of Agriculture, GKVK, Bangalore. The liquid bio fertilizer (5 ml) was mixed with equivalent quantity of 10 per cent jaggery solution for one kg of the seed and mixture has been coated uniformly on seed and exposed for drying in shade for 10 minutes before sowing for seed treatment (Trimurtulu and Rao 2014). The 625 ml of liquid bio fertilizer was used for one hectare of main field and was diluted with 25 litres of water and then mixed with 500 kg of powdered farm yard manure incubated overnight. This mixture was applied at the time of transplantation in the furrows below the seed surface (Khandare et al 2020) and for the seedling dip, 500 ml of liquid bio fertilizer mixed with 25 litres of water and the root portion of the seedlings meant for 1 hectare were dipped for 20 minutes just before transplanting (Poorniammal et al 2020). Fertilizers were provided through urea, di-ammonium phosphate and muriate of potash to meet nitrogen, phosphorus and potassium requirement, respectively of the crop as per the treatments. The observations on growth and yield parameters were recorded, nutrient uptake and available soil nutrients were computed. The soil available nitrogen was estimated by following the procedures of alkaline potassium permanganate method (Subbiah and Asija 1965). Available phosphorus in soil was calculated using Bray's method (Jackson 1967) while, the available potassium was using ammonium acetate and calculated using Hange's flame photometer (Jackson 1967). The count of bacteria was assessed using the serial dilution pour plate method (Gerhardt et al 1981) and the actinomycetes count was assessed using the serial dilution pour plate method (Nonomura and Ohara 1969). The number of fungi was counted using the serial dilution pour plate method (Kanwar et al 1997). The recorded data for different characteristics were subjected to statistical analysis adopting the method of analysis of variance.

RESULTS AND DISCUSSION

Plant growth parameter: Significantly higher plant height, tillers per plant and dry matter accumulation at harvest were with the treatment T4:100% RDF + Seed treatment + Soil application + Seedling root dip (103 cm, 4.2 and 52.12 g plant^{-1}, respectively) and was on par to T2:100% RDF + Soil application, T3:100% RDF + Seedling root dip and T8: 85% RDF + Seed treatment + Soil application+ Seedling root dip (Table 1). The higher growth parameter was due to better availability of nutrients which helped the plants to grow profusely. Similarly, rapid initiation of leaves and their expansion ultimately resulted in higher rate of photosynthesis besides higher dry matter accumulation of individual plants. These results are inconformity with the findings of earlier researchers (Meena et al 2013, Panwar et al 2014, Opera et al 2017 and Deepto et al 2022).

Grain and straw yield (kg ha^{-1}): The maximum grain and straw yield (4080 and 7810 kg/ha, respectively) was with 100% RDF + Seed treatment + Soil application + Seedling root dip, which was statistically superior over other treatments but was on par with T2, T3 and T8. However, significantly lesser grain and straw yield was noticed in T14: absolute control (1757 kg/ha and 3710 kg/ha, respectively) and T13:RDF(3245 and 6294 kg/ha, respectively) but T13 was on par with the T10:70% RDF + soil application and T11: 70% RDF + seedling root dip (Table 1). Increased in yield was attained due to overall improvement in crop growth, which further enabled the plants to absorb more nutrients, leading the plants to produce more photosynthates resulted in enhanced yield attributes and finally yield with integration of inorganic fertilizer and consortium. Similar results were obtained with the findings of Opera et al (2017) and Jat et al (2018) .

Nutrient uptake: The significantly higher uptake of nitrogen (76.57 kg/ha), phosphorus (36.40 kg/ha) and potassium (76.53 kg/ha) by finger millet was with 100% RDF + Seed treatment + Soil application + Seedling root dip (Table 1) but was with T2, T3 and T8). Significantly the lowest uptake of nitrogen, phosphorous and potassium (32.15, 18.15 and 56.73 kg/ha, respectively) was with absolute control (T14). T4 and T2 registered significant increases in N uptake by grain of 18.56 and 14.86 per cent and straw of 17.96 and 15.35 per cent; P by grain of 15.49 and 14.14 per cent and straw of 22.15 and 17.77 per cent and K by grain of 17.96 and 15.89 per cent and straw of 12.77 and 8.85 per cent, respectively over RDF. Higher nutrients uptake upon application of liquid bio fertilizer is mainly due to co-inoculation of associative nitrogen fixer (*Azospirillum lipoferum*), which fixes atmospheric nitrogen by association with roots whereas phosphorus solubilising bacteria(*Bacillus*

megaterium) and potassium solubilising bacteria(*Frateuria aurantia*) which can synergistically solubilised P and K in soil and make them ample available for the uptake by plant root and leading to plant growth (Sheng 2005) and also the impact of liquid bio fertilizer is that they are able to grow beyond the depletion zones around the plant roots and increase the uptake of immobile nutrients such as P and K and this result is in accordance with Chelvi (2017) and Deleep and Ravinder (2006) (Table 2).

Soil properties after harvest: Physico-chemical properties of soil *viz.,* pH, electrical conductivity and organic carbon after the harvest of finger millet was not influenced significantly due to various treatments (Table 2). The highest soil available nitrogen, phosphorus and potassium was recorded with application of 100% RDF + combined methods of application (seed treatment, soil application and seedling root dip) (244, 86 and 210 kg/ha, respectively) and followed by T2 and T3 (Table 2). Higher availability of nutrients when compared to RDF and absolute control might be due to microbes in consortia like *Azospirillum lipoferum* (Nitrogen fixer) which fixes atmospheric nitrogen in biological nitrogen fixation process. *Bacillus megaterium* (Phosphorous solubilising bacteria) which solubilizes native fixed P through release of various organic acids during microbial processes and *Frateuria aurantia* which help in solubilizing and mobilizing the native or non-exchangeable form of K and charge the soil solution with K ions, so that it may be readily available in the soil. Similar results are perceived by Sharma et al (2003). This result was also confirmed by the findings of Kamble et al (2018).

Soil Microbial Count at 50% Flowering

Bacterial count: Initial soil bacteria count before transplanting of finger millet was 10.60×10^6 cfu/g soil and which increased at 50% flowering and observed highest in T4 (52.30×10^6cfu/g) which was statistically significantly superior than other treatments (Table 4) and followed by T13 RDF recorded lower bacterial population (26.40×10^6 cfu/g) than all other treatments except 70% RDF + seed treatment and absolute control. Increased bacterial population was the result of production of root exudates due to the luxuriant growth of crop as reflected by higher dry matter production and finally resulted in higher microbial population and interaction of roots of a plant with its neighbouring plant might have increased the bacterial population with closer density. This result agrees with Badri and Vivanco (2009).

Fungi count: The fungi population was low initially (7.60×10^4 cfu/g soil) and subsequently increased during stage of 50% flowering in all treatments but the increase was relatively higher in liquid bio fertilizer treatments than absolute control. Application of 100% RDF+ Seed treatment + Soil application + Seedling root dip (T4) recorded higher fungi count (38.60×10^4cfu/g soil) which is significantly

Table 1. Influence of liquid biofertilizer consortium and its methods of application on Growth, Yield and Economics of finger millet (Pooled data of 2020 and 2021)

Treatments	Plant height at harvest (cm)	Tillers per plant	Dry matter accumulation (g/plant)	Grain yield (kg/ha)	Straw yield (kg/ha)	Net returns (Rs./ha)	B:C
T_1:100%RDF+Seed treatment	91.6	3.7	45.42	3625	7032	74178	2.96
T_2:100%RDF + Soil application	99.2	4.0	50.78	4025	7718	84668	3.14
T3:100% RDF + Seedling root dip	97.1	3.7	49.35	3938	7560	82520	3.11
T4:100% RDF + Seed treatment + Soil application+ Seedling root dip	102.9	4.2	52.12	4080	7810	84565	3.04
T5: 85 % RDF+ Seed treatment	83.9	3.3	40.78	3178	6260	61206	2.65
T6:85%RDF + Soil application	91.0	3.6	46.14	3590	7016	72137	2.85
T7:85 % RDF + Seedling root dip	89.5	3.5	44.71	3498	6885	69890	2.82
T8: 85% RDF + Seed treatment + Soil application+ Seedling root dip	95.2	3.8	47.48	3648	7038	72013	2.77
T_9:70%RDF+Seedtreatment	76.4	3.8	36.14	2735	5458	48301	2.32
T_{10}:70%RDF+Soilapplication	83.7	3.2	41.50	3148	6191	59226	2.55
T_{11}:70%RDF+Seedlingrootdip	81.9	3.0	40.07	3085	6035	57753	2.53
T_{12}: 85%RDF + Seed treatment+ Soil application+ Seedling root dip	87.6	3.3	42.84	3200	6208	58926	2.47
T_{13}:RDF (100:50:50 N,P_2O_5, K_2O kg ha^{-1}+ 375gazospirillum)	88.5	3.4	43.78	3245	6294	62400	2.65
T_{14}: Absolute control	65.1	2.4	29.27	1757	3710	29771	2.19
CD (p=0.05)	11.2	0.5	6.52	450	855	-	-

superior over other treatments but was at par with T2, T3 and T8. However, RDF) and absolute control treatment recorded lower fungi count than T4, T2, T3 and T8. Increased fungi population was due to root exudation which is positively correlated with root growth, which means actively growing root systems secrete more exudates that mediate positive interactions which include symbiotic associations with beneficial microbes, such as mycorrhizae, rhizobia and plant growth-promoting rhizobacteria (PGPR), thereby increasing fungi population. This result agrees with the studies of Garcia

Table 2. Nutrient uptake of finger millet as influenced by liquid biofertilizer consortium and its methods of application (Pooled data of 2020 and 2021)

Treatments	Nitrogen (kg/ha)			Phosphorous (kg/ha)			Potassium (kg/ha)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	45.46	22.86	68.32	16.65	15.45	32.1	46.65	22.25	68.9
T_2	49.48	24.95	74.43	18.56	16.95	35.51	48.95	24.75	73.70
T_3	48.12	23.92	72.04	17.95	16.16	34.11	48.25	23.56	71.81
T_4	50.71	25.86	76.57	19.25	17.15	36.4	51.25	25.28	76.53
T_5	40.62	20.36	60.98	14.85	14.25	29.1	42.35	19.28	61.63
T_6	44.68	22.35	67.03	16.76	15.75	32.51	46.35	22.08	68.43
T_7	43.32	21.42	64.74	16.15	14.96	31.11	43.95	21.06	65.01
T_8	45.91	23.15	69.06	17.18	15.95	33.13	47.86	22.78	70.64
T_9	35.82	17.86	53.68	13.05	13.05	26.1	38.05	16.78	54.83
T_{10}	39.88	19.85	59.73	14.96	14.55	29.51	41.35	19.75	61.1
T_{11}	38.52	18.92	57.44	14.35	13.76	28.11	39.65	18.56	58.21
T_{12}	41.11	20.65	61.76	15.38	14.75	30.13	43.56	20.28	63.84
T_{13}	42.23	21.03	63.26	15.76	14.85	30.61	43.75	20.67	64.42
T_{14}	20.15	12	32.15	9.85	8.3	18.15	43.25	13.48	56.73
CD (p=0.05)	6.25	3.95	7.55	2.50	1.60	3.50	5.50	3.25	7.25

See Table 1 for treatment details

Table 3. Physicho-chemical properties and nutrient status of soil after harvest of Finger millet as influenced by liquid biofertilizer consortium and its methods of application (Pooled data of 2020 and 2021)

Treatments	pH	EC (dsm^{-1})	Organic carbon (%)	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)
T_1	5.64	0.26	0.35	236	79	205
T_2	5.58	0.27	0.36	242	83	209
T_3	5.60	0.27	0.36	241	82	208
T_4	5.55	0.27	0.36	244	86	210
T_5	5.72	0.25	0.35	227	66	196
T_6	5.65	0.26	0.35	233	71	199
T_7	5.67	0.26	0.35	232	71	197
T_8	5.62	0.26	0.36	236	74	200
T_9	5.79	0.24	0.34	219	53	187
T_{10}	5.73	0.25	0.34	224	59	191
T_{11}	5.75	0.25	0.34	223	58	188
T_{12}	5.70	0.25	0.34	227	61	194
T_{13}	5.72	0.27	0.35	229	63	195
T_{14}	5.93	0.22	0.33	75	46	138
CD (p=0.05)	NS	NS	NS	31	10	28

NS-Non significant
See Table 1 for treatment details

Table 4. Bacterial, fungi and actinomycetes population as influenced by liquid biofertilizer consortium and its methods of application

Treatments	Bacteria (cfu/gX10^6)	Fungi (cfu/gX 10^4)	Actinomycetes population (cfu/gX10^3)
T_1	34.3	34.6	14.0
T_2	46.6	36.6	15.9
T_3	44.9	35.6	15.0
T_4	52.3	38.6	16.6
T_5	27.6	30.3	12.3
T_6	38.4	34.0	13.6
T_7	36.6	32.6	14.6
T_8	43.3	35.0	9.6
T_9	22.6	26.0	11.6
T_{10}	30.9	29.6	10.3
T_{11}	28.3	27.6	12.6
T_{12}	33.9	32.0	10.7
T_{13}	26.4	27.17	11.2
T_{14}	14.3	20.0	6.0
CD (p=0.05)	5.2	3.8	2.1

See Table 1 for treatment details

et al (2001), Saini et al (2004), Badri and Vivanco (2009).

Actinomycetes count: The T4 has recorded significantly higher actinomycetes count (16.60×10^3 cfu/g soil) than initial population (3.30×10^3 cfu/g soil) and was followed by T2, T3 and T8 which were on par with each other (Table 4). Increased actinomycetes population was owing to application of inorganic fertilizers together with liquid biofertilizers favoured the augmentation of microbial population. These results agree with the results of Arbad et al (2008), Padmaja et al (2012) and Goutami et al (2015).

Economics: The highest net return and benefit cost ratio was recorded with T2 treatment which was due to relatively reduced cost of cultivation, higher grain and straw yield and improved growth and yield attributes (Table 1). The results agree with the findings of Mishra et al (2015), Kishor et al (2017) and Patel et al (2018).

CONCLUSION

Over all, the application of 100% RDF +Seed treatment + Soil application + Seedling root dip exhibited higher growth, yield, nutrient uptake, available nutrient status in soil and more microbial population over RDF alone and absolute control treatments. However, the treatment comprising 100% RDF + soil application of liquid biofertilizer consortium emerged as the best treatment from the economical and practical perspective of the results obtained. Hence from the present investigation, 100% RDF with the soil application of liquid bio fertilizer consortium could be endorsed to augment the overall productivity of the system.

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Study on Soil Microbial Biomass Carbon and Variation due to Land Use and Season in Semi-Arid Region of Southern Andhra Pradesh

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***Abstract*:** Soil microbial biomass is the active and labile part of the soil organic carbon that constitutes living microorganisms smaller than 5-10 μm^3. These soil microorganisms play a key role in the release and retention of essential nutrients for plant growth. Soils in the semiarid region of the study sites are nutrient poor on which dry deciduous forests occur and alkaline nature of soils prevail in agriculture and grasslands. Chloroform fumigation extraction method was used to determine the soil microbial biomass (SMB) content in the four land use types and across three seasons. There was significant difference in SMB content across the four land use types and seasons. Maximum SMB content was recorded in agricultural land use (216.3 µg/g) followed by forest (174.37 µg/g), miyawaki plantation (124.38µg/g) and grassland (72.47µg/g). The higher SMB content was recorded in rainy season followed by winter and summer season. The study suggest that soil moisture conditions, soil organic carbon content influence the variation in the SMB content in these study sites.

***Keywords*:** Dry deciduous forests, Land use type, Soil organic carbon, Soil microbial biomass, Soil moisture

Soil microbial biomass (SMB) represents the living component of soil organic carbon (SOC), comprising mainly bacteria, fungi, actinomycetes, rotifers and protozoans up to 5 X 10^3 μm^3 size (Singh and Gupta 2018). In addition SMB forms only 1-5% of the SOC, but represents the major active and labile fraction of nutrients that are available to plants due to rapid turnover rate of less than one year (Brady and Weil 2013). SMB is inferred to play a key role in nutrient cycling through immobilisation and mineralisation of nutrients, by decomposing the plant litter, thus providing essential nutrients for plant growth and as well improving the soil quality by forming aggregates of<250µm diameter (Thakur et al 2022). The seasonal dynamics in regard to microbial biomass suggest that the SMB upholds the nutrients when they are in large amount and releases them when the plant growth is maximum (Bhattarai and Mandal 2020). The seasonal environmental conditions like soil moisture and temperature have a direct effect on microbial biomass cycle and these variables may also show influence indirectly on the SMB content by means of interaction with other factors like vegetation (Yang et al 2010), topography and landscape (Chang et al 2016) soil depth (Pal et al 2020). Thus factors such as topography (Bargali et al 2018), soil properties (Arunachalam and Arunachalam 2000), plant litter (Fang et al 2014), SOC content, land-use pattern and vegetation type (Lepcha and Devi 2020) influence the SMB variation. In India majority of the studies on SMB dynamics were carried out in humid regions like North western Himalaya (Singh et al 2018), Central forest Himalayan soils (Bargali et al 2018). In nutrient poor soils of semi arid region of Andhra Pradesh the information on Soil organic carbon (Ramana and Reddy 2019) is available but information on SMB dynamics was not carried out. Hence the main objectives of the present study were to analyse the variation in SMB values across the four land use types and across three seasons.

MATERIAL AND METHODS

The study was carried out in four land use types namely Guvvalacheru forest (GF;14˚16' 28.3" N 78˚51'57.6" E), Miyawaki plantation in Yogi Vemana University campus (MW; 14˚28'10.8" N, E 78˚42' 43.56,'), agricultural land (AG; 14˚28'10.8" N, 78˚42' 43.56 E) in which paddy and maize are grown and natural grassland in the Yogi Vemana University campus (NG; 14˚28'10.8" N, 78˚42' 43.56, E') in the semi-arid region of Kadapa district, Andhra Pradesh. All the four study sites feature a tropical monsoon climate with three distinct seasons namely summer (March to May), rainy (June to October) and winter seasons (November to February). Summer is very severe, while winter is mild and rainy season is moderately wet. The four study sites receive an average annual rainfall of 680 cm with a maximum of total rainfall occurs in the monsoon period of June to September. In the study sites, the mean monthly maximum temperature ranged between 28˚C to 44˚C and mean monthly minimum temperature range between 14˚C to 37˚C.

Soil samples were collected randomly at 0-15 cm depth in three replicates from the five 10X 10m quadrats laid in each of the four land use types in three different seasons. Soil

samples were thoroughly mixed to form a composite sample from each of the land use study sites. The collected soil samples were air dried and passed through 2 mm sieve for soil samples analyses. Soil moisture was determined by the oven dry method, soil temperature was measured by soil thermometer, soil pH and Soil Electrical Conductivity were measured by glass electrodes immersed in the 1:5 soil: water samples respectively. Bulk density was measured by estimating the dry weight of a unit volume of soil collected by inserting metallic box of known internal volume (Brady and Weil 2013). Soil Organic Carbon was measured by using strong oxidising agent potassium dichromate, soil samples digestion was done by Conc. H_2SO_4 and titrated with ferrous sulphate (Walkley and Black 1934). Soil microbial biomass (SMB) was measured by the flush of carbon released from soil in response to chloroform fumigation which corresponds to the total microorganisms present in the soil sample. In this Chloroform-Fumigation Extraction procedure, soils are exposed to chloroform vapour for 24 hours in order to kill and lyse the microbial cells with the release of cytoplasm into the soil. Then the carbon is extracted from soil by 0.5M K_2SO_4 solution in both fumigated (CF) and non-fumigated samples (CNF) and organic carbon in the extract was estimated by acid-dichromate oxidation procedure and the difference between CF and CNF is noted as SMBC (Vance et al 1987).

SMB (µg/g soil) = $E_{CF} – E_{CNF}/K_{E.C}$. [E_{CF} = Extractable 'C' in the Fumigated Soil; E_{CNF} = Extracted Carbon in Non-Fumigated Soil; $K_{E.C.}$ = 0.38].

Data analysis: The results obtained from the soil sample analyses were tested for normality and homogeneity of equal variance (Scheffe and Levene test ($F(11, 24) = 1.163$ $P>0.05$) respectively). Data transformation is not needed as the assumptions of normality and homogeneity of equal variance were met. Two-way ANOVA test was carried out to know the impact of the variation in land use types and seasons by measuring the significance level. Post–Hoc LSD (Least Significant Difference) test was undertaken to know the difference in SMB values among the four land use study sites. Pearson Correlation analysis was carried out to know the strength of the relation between SMB and Soil Moisture, Soil Temperature and SOC. Statistical tests were carried out by SPSS Version 20.

RESULTS AND DISCUSSION

Forest soils showed near neutral pH values (6.9-7.18), while alkaline nature of soils in the range of 7.42-8.85 in MW plantation and higher alkaline pH range was in AG (8.03-9.5) and in NG study sites (8.24-10.07). Similarly lower mean B.D. was in the forest followed by AG site and higher mean BD were registered in MW and NG sites. Higher mean SOC content was recorded in forest sites and nearly double the values recorded in the other three land use types. Thus reflecting a negative relationship between SOC and BD. SMB values varied with high mean registered in AG sites (216.3 µg/g) followed by forest site (174.37 µg/g) and lower were recorded in MW (124.38 µg/g) and NG (72.47 µg/g). Thus the varying litter content and root types are the prominent drivers that influence the SMB content (Lepcha and Devi 2020). The estimated range of the SMB in the present study (72.5-287.2 µg/g) are lower than Central Himalayan forest soils (Bargali et al 2018; 416-763 µg/g) sub alpine tropical montane forests (Arunachalam and Arunachalam 2000; 140-1320 µg/g). This kind of the variation in SMB content suggest that the differences in the litter quantity and quality, rhizosphere depth levels are the major factors that influence the microbial activity in the soil and in-turn microbial biomass levels (Fang et al 2014). The SMB values showed a strong relation with SOC, indicating that the higher availability of soil organic matter have led to higher microbial biomass in the order of AG>GF>MW>NG. Similar correlation between SMB and SOC and litter content producing higher microbial biomass in natural ecosystems was observed in the previous studies (Arunachalam and Arunachalam 2000; Lepcha and Devi 2020). Thus, in varied soil conditions, the soil systems with high organic inputs (freshly added SOC) tend to have higher microbial biomass content as they are preferred energy sources for microorganisms (Chang et al 2016).

The mean SM was higher in AG site followed by Forest and minimum values were recorded in MW and NG sites (Table 1). Thus the study revealed a significant positive relation between SMB and soil moisture as adequate soil moisture levels improve the microbes survival rate and as well increase their activity and biomass (Singh et al 2010). But a negative relation between SMB and soil temperature was noted. Interestingly, AG sites featured high SMB content even though they comprised of lower SOC than GF site but had high SM values. It suggests that when certain SOC value is reached, SM plays a key role in regulating the SMB levels as also observed in paddy cropland of Eastern Himalayas (Lepcha and Devi 2020). The maximum concentration of SMB was in rainy season followed by winter and dry summer was observed in all the four land use types. This trend is may be due to higher decomposition rate of litter and microbial activities by which nutrients are immobilised at higher rate during the active growth season (Bhattarai and Mandal 2020). Minimum SMB was in NG site in dry summer season. Seasonal variation revealed that higher reduction between rainy Vs winter seasons was observed in NG site and higher reduction between winter Vs summer recorded in MW sites;

Table 1. Soil characteristics of the four land use types (Mean±SE)

Land use	Soil microbial biomass (µg/g)	Soil organic carbon (%)	Soil moisture (%)	Bulk density (g/cm^3)	pH (Range)	Soil temp (Range) (°C)
Agriculture (AG)	216.29±16.35	0.50±0.03	7.63±2.40	1.30±0.04	8.03-9.5	24.5-43.3
Forest (GF)	174.37±12.51	0.98±0.20	6.43±2.23	1.24±0.03	6.9-7.18	30-35.7
Miyawaki Plantation (MW)	124.38±22.65	0.46±0.16	5.12±1.30	1.43±0.12	7.42-8.85	32.7-38.7
Natural Semiarid grassland (NG)	72.47±17.65	0.33±0.06	4.81±1.48	1.44±0.12	8.24-10.07	26.6-42.2

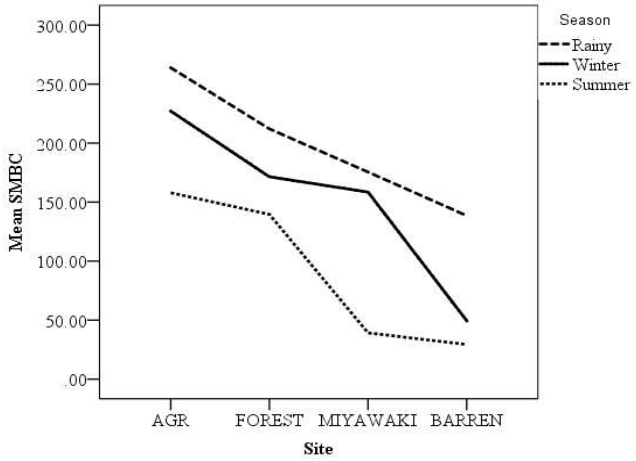

Fig. 1. Soil microbial biomass content variation across four land use types and three seasons

while forest site registered gradual decrease in SMB values from rainy season followed by winter and summer season (Fig. 1). The four land use patterns ($F_{3,8}$ = 73.81; P<0.05), three seasons($F_{2,6}$ = 71.94; P<0.05) and their interaction ($F_{6,24}$ = 3.83:P<0.05) have significantly influenced the variation in SMB content. The multiple comparison post Hoc (LSD) test indicated a significant difference across the four land use types except between forest and miyawaki sites and between rainy and winter seasons. Among all the four study sites, a peak value in SMB content was recorded during rainy season followed by winter and lower value in dry summer season. Similar trend showing higher SMB values in wet rainy season and lower content in winter season and summer season was noticed in North-Eastern deciduous forest; as wet conditions favours the microbial activities which increases the decomposition rates of litter (Lepcha and Devi 2020). The lower values in winter and summer season may be due to low microbial activity and slow rate of litter and organic matter decomposition (Yang et al 2010). But in tropical forests of Vindhyan plateau, the peak values of SMB were noticed during summer season (Singh et al 2010) and in humid forests higher SMB value was recorded in winter season (Arunachalam and Arunachalam 2000) which may arise due to the differences plant litter quality and rainfall pattern. Thus in the nutrient poor soils of the present study moderate soil temperature, moderate SOC levels and high Soil Moisture conditions support high SMB content in the rainy seasons and extreme temperatures in dry summer seasons leads to lower microbial activity and even death of microbial population.

CONCLUSIONS

The four different land use types in the semiarid region featured lower SOC content and varied SMB values and as well a positive relation between SMB and SOC. Agriculture study sites featured higher SMB values although it has relatively lower SOC values; while forest, Miyawaki plantation and grassland study sites revealed strong relation between SOC and SMB. Overall SM values seem to influence the SMB values with higher values in rainy season followed by winter and summer season. Thus a positive relation between plant growth and soil microbial activity was observed in these sites.

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Differential Expression of Metabolic Genes and Diversity of Soil Bacterial Community in Alluvial and Rocky Soil

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***Abstract*:** Microbes in soil primarily function to regulate nutrient cycle and maintain soil fertility. Extracellular enzymes produced by microorganisms breakdown organic material (for example, dead plants) into accessible nutritional components such as carbon (C), nitrogen (N), and phosphorus (P). This study showed that different soil ecology has distinct bacterial genera dominance and metabolic pathway to maintain soil nutrient cycle. The soil obtained from two agro climates zones/regions, i.e., Ralegan-Siddhi, Maharashtra (S1), and BBA University, Lucknow (S2), shows highly variable climatic conditions. Metagenomics tools used for prediction showed, *Fusobacterium* predominates in rocky soil, while *Flavisolibacter* predominates in alluvial soil whereas metabolic gene profiling shows dominance of the soil bacteria mainly for nitrogen and sulphur metabolism. Metabolic genes involved in the nitrogen cycle are more abundant in soil samples collected from alluvial soil, while genes involved in the sulphur cycle are more abundant in rocky soil. This study suggests that microbial diversity depends on the environment and functions in response to their surroundings.

***Keywords*:** Microbial diversity, Rocks, Metagenomics and metabolic pathway

Microorganisms are thought to be a major driving force in all the major nutrient cycles on earth, and this is especially true in the case of deserts, where plants are limited or non-existent. Microbes create enzymes that aid in the maintenance of various nutrient cycles in soil (Cavicchioli et al 2019). Hydrolases and oxidases are enzymes that breakdown substrates and release nutrients into the soil (Chukwuma et al 2020). Urease is an enzyme that catalyzes the breakdown of urea and is linked to microbial N uptake, 1,4-glucosidase is a hydrolytic enzyme that decomposes polysaccharides and is generated by soil bacteria and Phosphatases, both acidic and alkaline, are enzymes involved in the acquisition of phosphorus, and they cleave PO_4^{3-} from phosphorus-containing organic molecules (Wei et al 2018, Lasa et al 2019 and Svane et al 2020). The enzyme arylsulfatase hydrolyzes the organic sulphate esters catalyzes releasing SO^2 for plant use (Sekaran et al 2018). Numerous natural (i.e., geographical, physio-geological, or physicochemical properties of soils and anthropogenic (agricultural practices, waste discharge and mining) factors can influence microbial enzyme activities and production. Sun et al (2020) reported that soil pH, AP content, and the activities of the four enzymes were the most important factors influencing the soil bacterial community structure. Furthermore, as subsidence increased, so did soil nutrient content, enzyme activity, bacterial richness, and evenness (coal mining subsidence is classified according to geological hazards, groundwater contamination, and landscape damage) (Jing et al 2018). Climate, microbial biomass, and microbial community makeup, according to Waldrop, might influence the maximum rates of soil enzyme activity, potentially altering decomposition and nutrient mineralization rates in soils (Ali et al 2021). Phetcharat et al (2018) demonstrated the effect of inorganic fertilizers on the change of bacterial communities connected to the reservoir rock. The development of new molecular techniques in environmental microbiology over the last few decades has increased interest in understanding microbial systems' complexity, diversity and activity.Still, metabolic activity in the Rocky plateau zone remains unexplored (Wiseschart and Pootanakit 2020). In present used the metagenomics technique study to investigate bacterial enzyme activity in semi-arid rocky plateaus and arid alluvial soil. The current state of capabilities for accessing and predicting the catalytic potential of microbial communities, to capitalize on the use of biological activities for bio catalysis is discussed.

MATERIAL AND METHODS

Sample collection, DNA extraction and analysis: Soil samples were collected in sterile bags from the Ralegan-Siddhi site in the district of Ahmednagar, Maharashtra (S1), and the Net house of BBA University in Lucknow (S2). Commercially available kits were used to extract microbial DNA from samples. Amplification was performed using

QIAGEN and 40 ng of extracted DNA, as well as 10pM forward and reverse primers of the 16S rRNA V3-V4 region for bacterial and TAQ Master mix. For the amplification, we employed denaturation at 95°C for 15 seconds, annealing at 60°C for 15 seconds, elongation at 72°C for 2 minutes, and final extension at 72°C for 10 minutes. It was placed on hold at 4°C until the sequencing was completed. To prepare the sequencing libraries, Ampure beads were used to eliminate unwanted primers from each sample's amplicons, and an additional 8 cycles of PCR were done using Illumina barcoded adapters. Ampere beads were used to purify the libraries, and the Qubitds DNA high sensitivity assay kit was used to quantify them. Illumina Miseq with 2x300PE v3 sequencing kit was used for the sequencing. The KEGG database (https://www.genome. jp/kegg/) was used as reference data to align the representative sequences, and PICRUSt (phylogenetic investigation of communities by reconstruction of unobserved states) 1.1.0 analysis tool was used to perform detailed investigations at the genus level from single reads.

RESULTS AND DISCUSSION

In the present study used a metagenomics tool to understand the diversity of bacterial genera and functional gene annotation in two different geological soils i.e., rocky soil from Ralegan-Siddhi (S1) and alluvial from BBAU net house (S2). In the S1 sample, *Fusobacterium* is the most dominant genus, accounting for 20% of the top ten, followed by *Prevotella*, *Leptotrichia*, *Capnocytophaga* and *Neisseria* whereas in the S2 sample, *Flavisolibacter* (16%) was dominant followed by *Clostridium*, *Bacillus*, *Pseudomonas* and *Prevotella*. *Fusobacterium* and *Prevotella* are common in both soil samples and are among the top ten bacterial genera (Fig. 1). indicating vast diversity in the bacterial genera of present in soils, and rocky soil.

The PICRUSt 1.1.0 analysis tool and the KEGG database (https://www.genome.jp/kegg/) analyzed the microbial communities' functional gene annotation. Both soil samples show a higher abundance of genes involved in metabolic pathways, the S1 sample has a greater abundance of bacterial communities contributing to the N2 cycle, followed by the Sulphur cycle, than the S2 sample. The Ammonia oxidation (80.5 %), dehalogenation (40.9 %), nitrite reducer (37.7 %), nitrogen fixation (25.3 %), sulfate reducer (48.2 %), sulfide oxidizer (27.3 %), and lignin degrader have relatively higher abundance in soil samples (0.4 %) as compared to rocky soil. The pathways involved in chitin degradation account for 19.6 percent of the S2 sample, followed by Xylan degrader, aromatic hydrocarbon degradation. Atrazine metabolism, and sulphur oxidizer. The bacterial community involved in degradation pathways dominates the S2 sample, whereas the bacterial community involved in the Nitrogen and Sulphur cycle dominates the S1 sample (Fig. 2). The bacterial community present in the S2 sample are active in the nitrogen cycle compared to rocky soil and on other S1 community are most active in the sulphur metabolic pathway for which low availability of nitrogen and a good source of sulphur mineral in rocky soil is one of the reasons. Jia et al (2020) observed that N enrichment has either a positive, neutral or negative impact on soil microbial biomass in ecosystems. In soil and aquatic ecosystem, the significance of bacteria in the nitrogen cycle has been widely studied, but

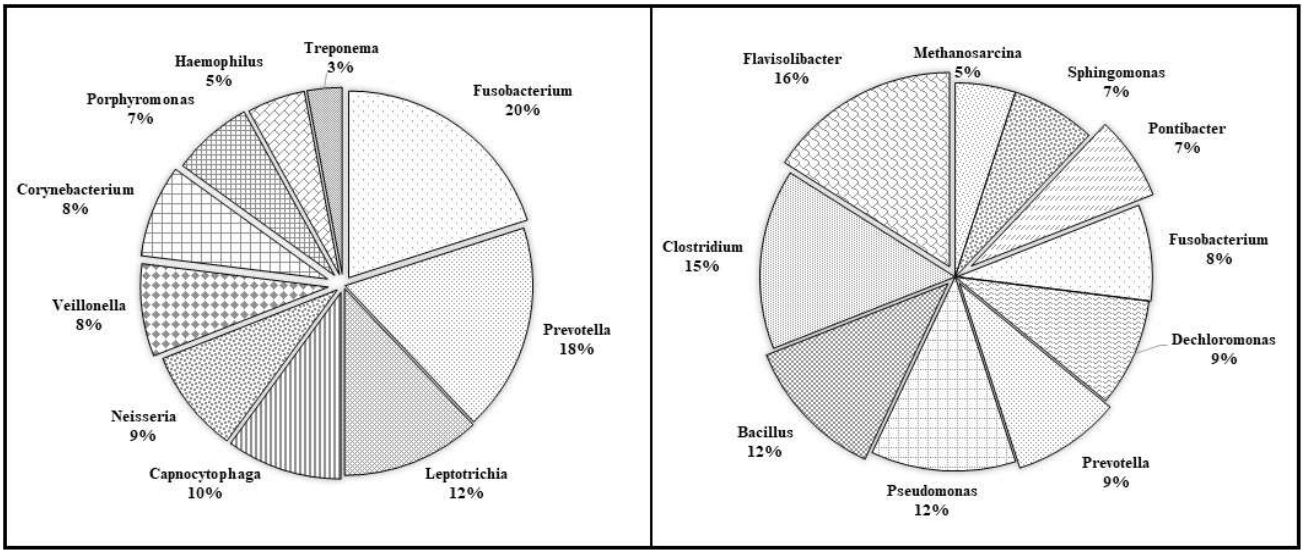

Fig. 1. Bacterial genera predicted in metagenomics analysis. (a) Rocky soil from Ralieh-gan siddhi, Maharashtra and (b) Alluvial soil from BBAU, Lucknow

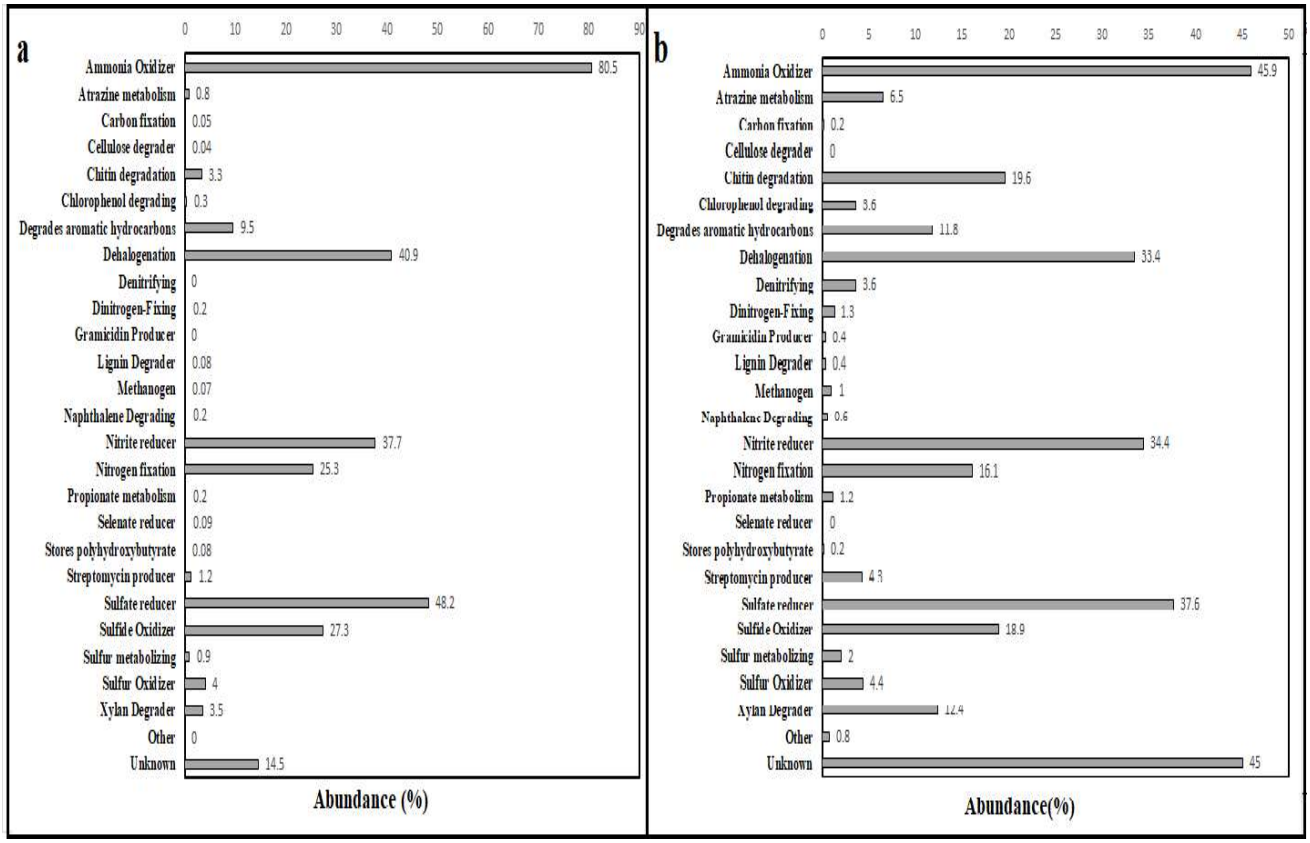

Fig. 2. Abundance of bacterial metabolic gene in different soil sample. (a) Rocky soil from Ralieh-gan siddhi, Maharashtra and (b) Alluvial soil from BBAU, Lucknow

knowledge of cave sediment is limited., Zhu et al (2019) concluded that microorganisms in oligotrophic conditions can acquire both energy and nutrients through nitrogen cycling activities. This research uncovered the majority of the nitrogen cycle genes. The presence of hydroxylamine oxidase genes shows that a crucial ammonia oxidizing bacterium is present. Lithochemotrophy may be a survival strategy for the bacterial communities on the rocks' sediments, as evidenced by the presence of ammonia oxidizing bacteria and sulfur-oxidizing bacteria in chemolithotrophic rocks (Flood et al 2021). Autotrophic nitrification has been discovered in *Nitrospira* and *Nitrosospira* indicating a CO2-fixation-coupled ammonia oxidation process in the studied ecosystems (Alfreider et al 2018).

CONCLUSION

Soil from Ralegan-Siddhi in Maharashtra and at BBAU in Lucknow were substantially different in every way, and metagenomics data revealed a significant difference in bacterial community diversity in both samples. The organisation of the bacterial population is influenced by environmental factors, and they express their metabolic activity accordingly. Understanding microbial diversity and metabolic gene prediction can aid in comprehending the environment from which they were isolated, as well as forecasting soil microbial ecology succession in evolution and microbe relationships.

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Exploitation of Cellulase Producing Bacterial Strains from Mangrove Soils for Rapid Composting of Leaf Litter

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Abstract: Climate change has become unavoidable due to the increase in carbon dioxide emissions all over the world. The best way to counter this is would be increasing the tree cover. Reforestation or afforestation leads to accumulation of leaf litter which can be used as a source of composted fertilizer obtained by the decomposition taking place naturally at the site itself but it is observed that certain bacterial strains are capable of rapidly decomposing the leaf litter and converting it to nutrient rich compost and this is the need of the hour. In the present investigation cellulose producing bacteria were isolated from the soil samples collected from Pichavaram in Tamil Nadu, India, which is mangrove forest area, rich in micro-organisms that break down woody branches and fallen leaves in a saline environment. The bacteria isolated were screened for cellulase activity both qualitatively and quantitatively and out of the 20 isolates, 15 tested positive for cellulase activity. Of these two strains BN2 and BN11 showed highest activity and highest level of quantified enzyme. These two strains were used to inoculate leaf litter to bring about decomposition and compared to a control that was allowed to decompose naturally. The composting was completed in 45 days in the treated set up as compared to the natural composting that took about 120 days. The generated composts were analysed for nutrients and phytohormones at regular intervals from 30 days onwards which was gradually increasing showing a maximum in compost generated by the bacterial strain BN2 and minimum in the naturally generated compost. This study is significant in helping to identify a rapid composting method as well as providing a source for producing an industrially important enzyme namely cellulase.

Keywords: Compost, Nutrients, Phytohormones, Mangrove forest, Industrial enzyme

Forests play an important role in the maintenance of the biological equilibrium and act as the lungs of the planet. Raising forests has become very essential as environmental degradation is taking place at an accelerated rate. Whatever forests are available serve as a source of leaf litter that can be put to good use if properly processed. Leaf litter and other woody wastes generated in forests is naturally decomposed by the soil microbes and results in the cycling of nutrients. But in areas where tree density is high, it becomes necessary for the periodical removal of litter and a faster means of composting would yield commercially valuable manure. Areas like Mangroves have a concentration of salt in the substratum with an enormous production of woody wastes on a daily basis. Mangroves as an ecosystem are highly productive and here bacteria are involved in bio-mineralisation and biotransformation of biological wastes (Gonsalez-Acosta et al 2006). The major products of recycling include the detritus which is rich in a large microbial population helping in the cycling of carbon, sulphur, phosphorus and nitrogen (Rojas et al 2001). About 30 to 50% of the organic matter of mangrove leaves have tannins and sugars that are leachable and the remaining is the structural component having cellulose which is a linear polysaccharide composed of glucose units linked by 1-4glycosidal linkages.

The carbon and energy for the animal consumers is transferred from mangrove detritus through the grazing of lignocellulosic material decomposed by the bacterial and fungal populations in the detritus. These microbes have an enzyme called cellulase that is able to degrade cellulose and are important enzymes used in the food, feed, textile and pulp industries (Behera et al 2014). Hence the present study was undertaken to identify cellulase producing bacterial strains from Pichavaram, a mangrove forest located 250 kilometer from Chennai, Tamil Nadu, India, and to screen them for production of the enzyme cellulase and utilize the prospective strains for rapid composting of leaf litter.

MATERIAL AND METHODS

Sampling location and sample collection: Pichavaram is a village near Chidambaram in Cuddalore district, Tamil Nadu, India. It is located between the Vellar estuary in the north and Coleroon estuary in the south. This Vellar-Coleroon estuarine complex forms the Killai backwaters and the mangroves are rooted in three to five feet in water having geographical location is latitude 11°29'N and longitude 79°46'E. The soil samples were collected from different locations of the mangrove forest which were chosen based on the presence of degrading plant litter at a minimum

distance of 1000 m between the sampling sites. About 100 g of the collected samples were stored at 4°C in sterile containers, ensuring the samples are free from unwanted materials. Nutrient Agar was the medium used for culturing the bacteria in the samples and the cultured bacteria were subjected to serial dilution and plating to obtain pure cultures that could be screened for cellulolytic activity

Cellulolytic bacterial screening: To screen for cellulolytic organisms, the isolates were grown in minimal agar plate consisting of yeast extract (0.2%), KH_2PO_4 (0.1%), $MgSO_4$ (0.5%)and carboxy methyl cellulose (CMC) -(0.5%). Negative control plates inoculated with laboratory *E. coli* strain (HB101) were included in all tests. The test plates were incubated at 30°C for 2 days. The hydrolysis zones were visualized by flooding the plates with an aqueous solution of Congo red (1 mg/ml) for 15 minutes and washed with 1M NaCl (Teather and Wood 1982). Cellulolytic organisms produced a clear zone around the colonies because of the digestion of carboxy methyl cellulose (CMC) the zone of digestion was measured and documented.

Cellulase enzyme activity assay: Carboxy methyl cellulase activity was assayed using methods described by Mendells and Weber (1969). The activity was estimated using 1% solution of carboxy methyl cellulose in 0.05 M citrate buffer (pH 4.8) as substrate. The reaction mixture contained 0.5 ml of substrate solution and 0.5 ml of suitably diluted enzyme solution and reaction was carried out at 50°C for 30 minutes and the reaction was stopped by adding 3 ml of DNS solution to the reaction mixture. The reaction mixture was then boiled at 100°C for 5 minutes. The optical density was taken at 540 nm. One unit of carboxy methyl cellulose activity expressed at 1µmol of glucose liberated per ml of enzyme per minute. The values were compared with a glucose standard curve.

Method of composting: Pot study was carried in the laboratory to produce the compost by setting up the vermicompost, bacterial compost and natural compost system each in separate pots. Vermibed was prepared with a layer of good moist loamy soil of 5 cm thickness placed at the bottom and above it coarse sand and broken bricks of 4 cm thickness were placed with small holes drilled at the bottom for air circulation and drainage. The pots were of equal size with 60 cm height and circumference of 36 cm at bottom and 88 cm at the top. In each pot 3 kilogram of substrate (leaf litter) was used for all the treatments. Twenty-five adult individuals of *Eudrilus euginae* (earthworms) were introduced on the top of the substrate for vermicompost and 10 ml of bacterial inoculum was added in the bacterial composting setup. The third pot which was the control contained only the substrate. The process of composting in the 3 setups were carried out until the leaves were completely decomposed.

Physico-chemical parameters: The pH of the compost was measured using a digital Ph meter and electrical conductivity using an electrical conductivity meter. Mineral nutrients like phosphorus was determined using the method of Cook (1997), potassium and calcium by the method of Kalra (1971).

Quantification of plant growth regulators (PGR's): Extraction and estimation of growth regulators like indole acetic acid (IAA), gibberellic acid (GA3) and kinetin (KN) in the 3 extracts of generated composts were performed according to the method of Unyayar et al (1996).

RESULTS AND DISCUSSION

The sampled soil when cultured on nutrient agar medium showed the presence of different bacterial strains. 20 colonies with varying morphology were selected from the mother plate and subculture on nutrient agar plates using quadrant streaking method. Pure colonies were obtained in all the 20 plates after 24 h of incubation.

Bacterial screening Of the isolated bacterial strains, 15 cultures showed cellulolytic activity on CMC plates. The highest zone of 2.1 cm was observed in strains BN2 and BN20 while a zone diameter 2 cm was formed in strain BN11 followed by strains BN13 and BN16 that each showed a zone of 1.9 cm in diameter. The least zone of digestion was observed in strain BN19 while strains BN 5, BN 6, BN 10, BN 17 and BN18showed no zone of digestion and were not used for further analysis (Table 1). Padhan et al (2023) have isolated cellulase producing bacteria like *Pseudomonas flourescens*, *Bacillus subtilis* and *Serratia macrescens* from the soil and studied the factors affecting cellulase production.

Quantification of cellulase enzyme activity: In the present study, 15 strains that showed cellulolytic activity in the plate method were subjected to enzyme quantification studies by spectrophotometric assay. The strain BN2 had the highest cellulase activity of 0.521 U/ ml followed by the strain BN11. The activity in strain BN20 was 0.489 U/ ml and the least was observed in strain BN19 (0.245 U/ml) (Table 2). Gupta et al (2012) recorded a cellulase activity ranging from 0.162 IU/ ml to 0.400 IU/ ml . Sreena et al (2016) reported an activity level of 5.06 U/mg for *Bacillus cereus* isolated from termites. Ali et al (2019) have screened bacteria from a sub-terranean species of termite and the cellulase activity of the 5 isolated strains ranged from 0.1U/ ml to 1.47 U/ ml. Bhagat and Kokitkar (2021) have isolated cellulose degrading bacteria from the soil and have optimized the cellulase activity.

Composting: Among the different strains, the one that had high cellulolytic activity with high level of cellulase enzyme was strain BN2 and this was used to bring about composting of leaf litter. This was compared with vermicomposting and natural composting.

Treatment I: Natural composting: The setup containing only leaf litter was allowed to undergo decomposition naturally, and at the start of the experiment the temperature of the substrate was high and then decreased gradually from 34°C to 26°C, stabilizing at 25°C and composting was completed in 120 days

Treatment II: Leaf litter treated with earthworms (*Eudrils euginae)* for vermicomposting: At the start of the experiment, the temperature rose to 34°C and decreased to 23°C on maturation and composting was completed in 90 days.

Treatment III: Leaf litter treated with bacterial strain BN2: The temperature was high initially and rose up to 35°C and then it fell gradually reaching 22°C with a stable pH. The composting was completed in 45 days.

Physico-chemical parameters of the generated composts: The study of the physico-chemical parameters revealed that there was a progressive decrease in pH and increase in electrical conductivity as composting progressed and this was more in the case of bacterial composting. The nutrients in the bacterial compost including calcium, phosphorus and potassium were in the bacterial compost as compared to vermicompost and natural compost (Table 2). The level of plant growth regulators (PGR's) was high in the bacterial compost in comparison to the other composts generated (Fig. 2a to 2c).

Completion of the composting process is revealed by the lowering of temperature and then the stability of temperature and pH, increase in the C/N ratio and an increased germination index as reported by Oktiawan et al (2018). The use of microbial inoculants to reduce composting time has been earlier reported by Pan et al (2012). The fall in temperature of

Table 1. Zone of digestion in CMC agar plates showing cellulase activity

Isolate	Zone (cm)
BN-1	1.8
BN-2	2.1
BN-3	1.8
BN-4	1.8
BN-5	0.0
BN-6	0.0
BN-7	1.3
BN-8	0.7
BN-9	1.5
BN-10	0.0
BN-11	2.0
BN-12	1.4
BN-13	1.9
BN-14	0.8
BN-15	2.0
BN-16	1.9
BN-17	0.0
BN-18	0.0
BN-19	0.5
BN-20	2.1

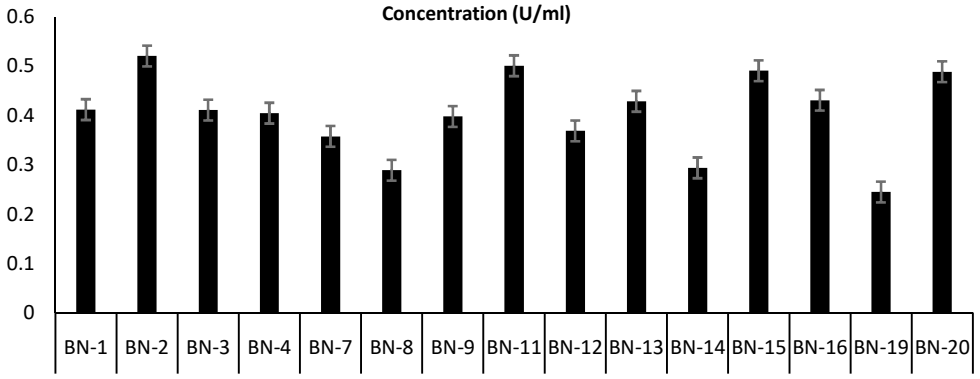
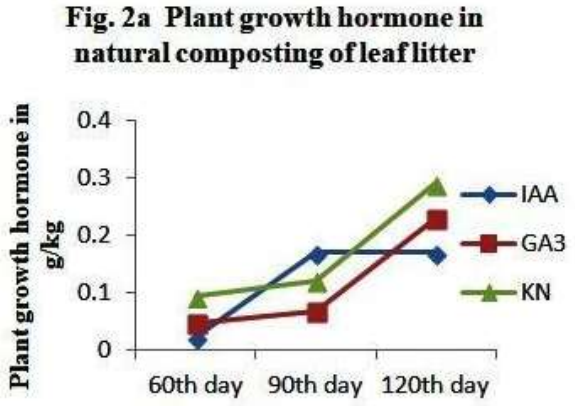
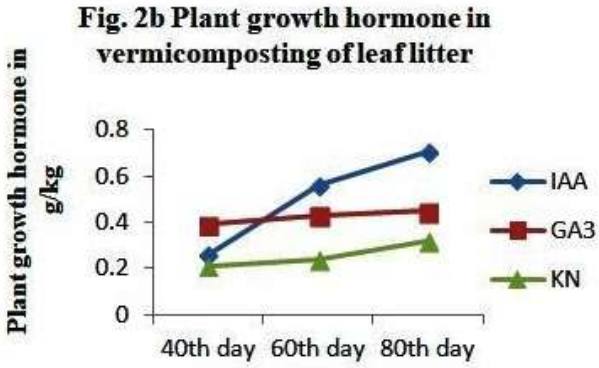


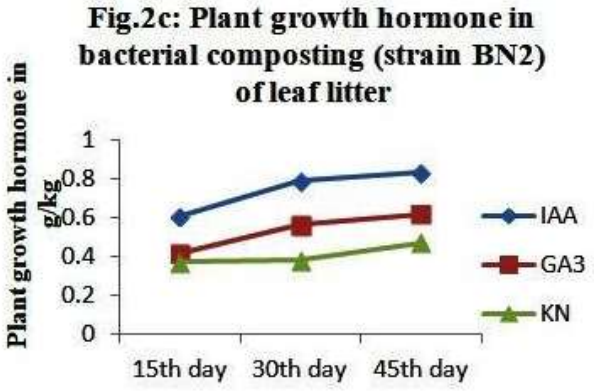
Fig. 1. Quantification of enzyme cellulase from the selected isolates

Table 2. Physico-chemical properties of the generated composts

Treatment	pH	EC (µS)	Phosphorus (P) mg/gm	Potassium (K) (mg/gm)	Calcium (Ca) (mg/gm)	Nitrogen (mg/gm)
Control (110th days)	6.3	1.29	0.29	0.273	0.192	0.49
Treatment I (80th)	5.9	1.31	0.063	0.341	0.319	1.97
Treatment II (42nd day) strain BN2	5.7	1.43	0.13	0.49	0.671	2.41







the compost indicates low microbial activity and the low amount of organic material as was converted to inorganic nutrients. This is evident from the high level of mineral nutrients present in the composts. This has also been observed in the earlier studies of Zakriya et al (2018) during the composting of rice straw. The pH according to them, varies from day1 to day 30 and is on the increasing trend due to decrease in organic matter. In the present study the decrease in pH in the bacterial compost was due to the high lignin content of the leaf litter used for composting (Toumela et al 2000). Athirai et al (2021) have shown increased level of micronutrients like phosphorus, potassium and calcium and have attributed this to the speedy mineralization brought about by composting which has also been further confirmed by Alade et al (2019)

CONCLUSION

The isolates BN2 and BN11 have high cellulase activity and can be effectively used as a potential source for industrial production of enzyme cellulase. The use of these strains can help in bioethanol production from cellulose containing bioresources. Moreover the strain BN2 has been effective in rapid composting of high lignin-containing leaf litter to produce nutrient-rich compost which would be a boon to sustainable agriculture in the present day.

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Exploring *Barilius bendelisis*: Unveiling as Potential Member of SIS Family

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***Abstract*:** Aquaculture and Fisheries encompass sectors that not only fulfill basic sustenance needs but also contribute significantly to enhancing the overall quality of life for humanity and generating foreign exchange. In the Eastern Himalayan region of Cooch Behar in West Bengal, India, renowned for its rich freshwater fish diversity, the *Barilius bendelisis* (Hamilton 1807) species holds high value both as an ornamental fish, also source of food and considered as SIS (small indigenous species). The classification of *Barilius bendelisis* (Hamilton 1807) as endangered and vulnerable in the Cooch Behar region is predominantly attributed to deteriorating water quality resulting from human activities, leading to a substantial decline in biodiversity. The physicochemical properties of the water significantly affect the biology and physiology of these fish. *Barilius bendelisis*, a small native fish species, is a popular source of sustenance in the Terai region of the Eastern Himalayas. The proximate analysis of *Barilius bendelisis* also established that it is a good source of protein needs. The Barcode ID number assigned to the studied *Barilius bendelisis* species is BOLD: AAF3096. The study offers foundational information about the biodiversity in the transboundary rivers Torsa, Raidak-1, and Mansai (Jaldhaka), which could prove invaluable for the conservation and management of *Barilius bendelisis*.

***Keywords*:** Aquaculture, Terai region of Eastern Himalaya, *Barilius bendelisis*, Proximate analysis, DNA barcoding, SIS (Small Indigenous Species)

India boasts a rich diversity of freshwater fish, encompassing 868 distinct species. Among these, 192 are considered endemic, while 327 species face threats according to the IUCN. The Genus *Barilius*, often referred to as Bariline fishes, typically resides in swiftly flowing mountain streams across Asia (De et al 2021). *Barilius* species are recognized by their flattened bodies, along with blue-black markings on their bodies and dorsal fins placed behind the midsection of their bodies (Hamilton 1822). *Barilius bendelisis* can be grouped as 'SIS' (small indigenous species). SIS can develop most extreme to a length of 25-30 cm in the development or grown-up phase of their lifecycle (De et al 2021a) .Globally, there have been reports of 36 fish species of *Barilius* genus, with 24 of them found in India (Qin et al 2019). According to the Conservation Assessment and Management Plan report for India's freshwater fishes, the conservation status of Barilius species is labeled as 'lower risk near threatened' (LRnt) (Molur and Walker 1988).

One such species, *Barilius bendelisis*, locally holds significance both economically and ecologically due to its ornamental value and potential as a food fish (Mishra et al 2012). However, despite its importance, *Barilius bendelisis* is experiencing a rapid decline in regions like the transboundary rivers Torsa, Raidak-1, and Mansai (Jaldhaka) in West Bengal, India, primarily due to overfishing, habitat degradation, alterations in hydrology and water pollution (Saha et al 2022a). In recent years, *Barilius bendelisis* has become increasingly scarce in these sub-Himalayan transboundary rivers (Saha et al 2022). Furthermore, the identification of Barilius species, including *Barilius bendelisis*, has been a significant challenge due to the species' high phenotypic variability, sexual dimorphism, and a lack of adequate identification keys for their immature stages (Mishra et al 2012). The transboundary rivers Torsa, Raidak-1, and Mansai (Jaldhaka) originate from the Sikkim, Darjeeling, Bhutan, and Tibetan Himalayas, ultimately entering Bangladesh through West Bengal, India (Fig. 1).

Over the past fifteen years, molecular tools, particularly DNA barcoding, have proven highly effective in cataloging fish diversity worldwide, including within India (Saha et al 2021). Beyond species identification, DNA barcoding has emerged as a valuable tool for resolving complex taxonomic issues in fish, such as species groupings and hidden diversities (Laskar et al 2013, Laskar et al 2018). However, the majority of integrated studies in this realm have been limited to characterizing the ichthyofaunal diversity in various riverine ecosystems in India. The current study seeks to bridge this research gap, particularly concerning *Barilius* species, with a special focus on *Barilius bendelisis*. This research aims to shed light on the phylogenetic relationships and genetic differences within these species, utilizing both newly generated and existing COI sequences from India.

MATERIAL AND METHODS

Barilius bendelisis specimens were obtained from three different locations along the Torsa river, Raidak-1, and Mansai (Jaldhaka) in West Bengal (Fig. 1.1, 1.2, 1.3). In the GIS layouts presented in Figures 1.1, 1.2 and 1.3, ArcGIS software has been used.

These specimens were captured using a cast net and authenticated based on established taxonomic references (Jayaram 2010). Following both morphological and molecular examinations, the specimens were preserved in a solution of 10% formalin. The voucher specimens have been stored in the laboratory at NBFGR, India. Aseptically collected muscle tissue from the specimen was stored at NBFGR, India, for future reference. Genomic DNA was extracted and PCR was conducted with published primer pairs: COIF1 and COIR1 (Saha et al 2021) using the Thermal Cycler. The PCR products underwent purification and sequencing according to the protocol (Laskar et al 2018). Bi-directional chromatograms were scrutinized through MEGA6 (Tamura et al 2013) to remove any noisy segments and generate consensus sequences. Online tools, such as BLAST and ORF finder, were employed to identify insertions/deletions (indels) and stop codons. The sequences were further cross-referenced with NCBI and BOLD databases. The final dataset comprised 66 COI sequences of Barilius, which included the newly generated sequences by us for *Barilius bendelisis* (NCBI accession no. MN810961, MN810962, MN810963, MN810964, MN810965, MN994439, MN994440, MN994441, MN994442). *Tor* (NCBI accession no. JX983505) served as

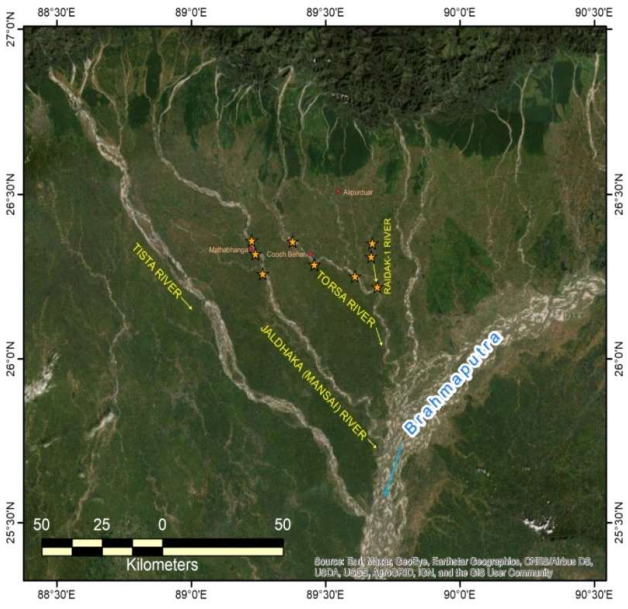

Fig. 1. Torsa, Raidak-1, and Mansai (Jaldhaka) River

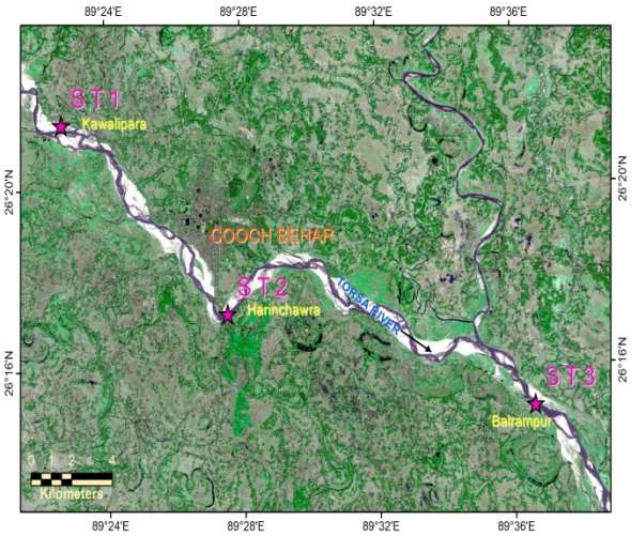

Fig. 1.1. GIS layouts of sampling spots at Torsa River

Fig. 1.2. GIS layouts of sampling spots at Raidak-1 river

Fig. 1.3. The GIS layouts of sampling spots at Mansai (Jaldhaka) river

the out-group in our study. Alignment of the dataset was accomplished using ClustalX software, and genetic divergence was calculated in MEGA6 utilizing the Kimura-2-Parameter (K2P) model. To assess species delimitation following the reciprocal monophyletic criterion, Bayesian analysis (BA) was conducted. The best-fit model, GTR+I+G, was determined using Partition Finder version 1.1.1 with the lowest Bayesian Information Criterion score. MrBayes 3.1 (Ronquist and Huelsenbeck 2003) was employed for BA, with Markov Chain Monte Carlo (MCMC) runs extending to 10,000,000 generations, with tree sampling every 100 generations (the first 1000 trees were discarded as 'burn in'). Convergence of the MCMC analysis was confirmed when the standard deviation of split frequencies fell below 0.01, and the potential scale reduction factor (PSRF) approached 1.0. The resulting BA tree was visualized using the web-based tool Interactive Tree Of Life (iTOL) (Letunic and Bork 2007).

RESULTS AND DISCUSSION

The worldwide practice of combining classical taxonomy and DNA barcoding has been widely embraced to shed light on various aspects of species diversity, including cryptic diversity, species complexes, and the pathways of invasion by invasive species (Tyagi et al 2017, Saha et al 2021). In present study, generated COI sequences of *Barilius bandelisis* collected from the Torsa, Raidak-1, and Mansai (Jaldhaka) Rivers in West Bengal, India. The final dataset consisted of approximately 648 base pairs, encompassing 67 nucleotide sequences representing 10 different *Barilius* species. *Tor* (NCBI accession no. JX983505) was used as an out group species. The Bayesian analysis (BA) phylogeny demonstrated that our generated sequences formed coherent clusters alongside the sequences from the reference database. Within the phylogenetic tree, 11 distinct lineages were discerned among the 10 morphospecies, including multiple clades within *Barilius bandelisis*. The overall mean genetic divergence in our dataset was estimated to be 6.1%., the highest mean intraspecific genetic divergence (17.1%) was observed within *Barilius bandelisis*. The two clades of *Barilius bendelisis* showed an average genetic divergence of 2.3% in our dataset. The Barcode ID for the *Barilius bendelisis* specimens was recorded as BOLD: AAF3096. This study underscored the effectiveness of DNA barcoding in distinguishing Barilius species at the individual level and contributed to our comprehension of *Barilius bendelisis* across various river segments in the northern region of West Bengal, particularly focusing on the Cooch Behar district of West Bengal, India (Saha et al 2021).

CONCLUSION

The identification of several distinct groups within the *Barilius bendelisis* species, each exhibiting considerable genetic divergence, suggests the presence of concealed variations and the potential emergence of separate species of *Barilius bendelisis* in different regions of eastern, north-eastern, central, and northern India. Nevertheless, to substantiate this hidden diversity, further taxonomic examinations employing multiple molecular markers are imperative. This research serves as an initial endeavor to gauge the genetic disparities within the said genus in India. The study will help to supplement the global database with barcode sequences of accurately identified *Barilius bendelisis*. Climate change, pollution, and habitat degradation have all had a significant impact on freshwater biodiversity, posing an extinction risk.

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Evaluation of Elite Cluster Bean [*Cyamopsis tetragonoloba* (L.)Taub.] Genotypes for Vegetable and Gum Purpose in Northern Dry Zone of Karnataka

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Abstract: The study was conducted on evaluation of elite cluster bean [*Cyamopsis tetragonoloba* (L.)Taub.] genotypes for vegetable and gum purpose in the northern dry zone of Karnataka during *rabi* season at College of Horticulture, Bagalkot, Karnataka with twelve genotypes collected form difference sources. All genotypes showed significant difference for all the characters studied. The maximum per cent of germination was in CAZG-06-1 (94.44%), Pusa Navabahar (86.44 cm) was the tallest among the genotypes and Gujarat Local (7.44) recorded higher number of branches per plant. Rajendra Nagar Local and Jodhpur Local took least number of days (22.00 days each) for initiation of flowering. Highest pod yield (158.72 q/ha) was in CAZG-06-1 followed by IC-11704 . The dry pod yield per plant and seed yield was significantly higher in CAZG-06-1. CAZG-06-1 was also superior with respect to gum content (32.86%). The highest protein content was in Rajendra Nagar Local (38.33%). The least crude fibre content was in AVT-II- GR-4 (4.10%). Pod yield per hectare was highly significant and positively correlated with number of pods per cluster (0.933), 100 seed weight (0.792) and ten dry pod weight (0.679). Dry pod yield per plant was highly significant and positively correlated with guar gum content (0.583), number of dry pods per plant (0.830) and number of seeds per pod (0.605). Seed yield per plant was significant positive correlation with dry pod yield per plant (0.594), 100 seed weight (0.706), gum content (0.579) and number of branches per plant (0.621). All cluster bean genotypes were moderately susceptible to powdery mildew except PusaNavabahar and Rajendra Nagar Local which were susceptible to powdery mildew. Economics of different genotypes revealed that highest net profit from CAZG-06-1 genotype followed by IC-11704 and RGC-1047.

Keywords: Cluster bean, *Cyamopsis tetragonoloba* (L.) Taub, Gum content, Dry pod yield, Protein, Crude fibre

Vegetables play a vital role in nutritional security of mankind being reliable sources of necessary vitamins, minerals, amino acids and fair amount of fibres. A large number of underexploited leguminous species have a great potential in contributing nutritious food, feed and forage needs in the tropical countries even though almost half of the population are under malnourished (Maphosa and Jideani 2017). Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] is one of the important underexploited leguminous vegetables belonging to family Fabaceae. Guar is a drought tolerant, hardy, deep rooted and multipurpose legume plant mainly grown for tender vegetable and seed endospermic gum in arid and semi-arid regions of India. Seed of cluster bean with large endosperm contains galactomannan type of gum, which forms a viscous gel even in cold water and has diversified industrial applications *viz.,* paper, food, cosmetics, mining, petroleum, well drilling, textile and jute, pharmaceuticals (Senapati et al 2006, Pathak et al 2009). Cluster bean gum has emerged as the most important agro-chemical, which is non-toxic, eco-friendly and generally recognized as safe (GRAS) by Food and Drug Administration (FDA). In India, cluster bean crop is cultivated mainly during *kharif* season. It occupied an area of 31.40 lakh hectare with a total production of 15.19 lakh tons of guar seed during 2019-20 in the country (Anonymous 2020). The country exports over 1.17 lakh tons of guar and its derivatives annually. India is the major exporter of guar gum to the world and exports various forms of Guar products to a large number of countries. The country has exported 234,872 MT of guar gum to the world for the worth of Rs. 1949 Crores during the year 2020-21 (Bajwan *et al*., 2023).

Looking to the multidimensional application of cluster bean as a vegetable and industrial crop which has wide adaptability under arid drought conditions, there is a prime

need for its improvement. Breeding varieties suited to specific agro-ecological conditions for vegetable and seed gum purpose is urgently needed for northern parts of Karnataka (Zone 2 and 3). Though, Central Arid Zone, Bikaner and other institutes have developed and identified certain guar genotypes for dual purpose but they have not been exploited and confirmed for their potentiality under varied agro-climatic conditions. Hence, there is a urgent need for identification of local as well as superior genotypes with respect to tenderness and dual purpose which are suited for northern dry zone of Karnataka. Therefore, the present study was undertaken to evaluate the performance of cluster bean genotypes for growth, vegetable pod yield and seed yield, to determine the association of seed yield with other contributing parameters, to analyze the seed gum, protein content and other quality parameters in cluster bean genotypes.

MATERIAL AND METHODS

Experimental site: The experiment was carried out at College of Horticulture, Bagalkot (Karnataka). The chemical properties of the soil from experimental plot are presented in Table 1. The pH of soil is 7.20 with 178.78 kg per hectare of available nitrogen, 29.00 kg per hectare of available phosphorus and 236.00 kg per hectare of available potassium.

Location and climate: Bagalkot falls under agro-climatic zone-3 northern dry zone of region-2 of Karnataka situated at 16°46' North latitude, 74°59' East longitude and at an altitude of 533.00 meters above the mean sea level. It has the benefit of both South-West and North-East monsoons. The temperature of this area ranges from 16.24^{0}C to 30.50^{0}C and relative humidity from 38.06 to 88.46 per cent with a rainfall of 147 mm during the experimental period (2021-22) as per the observation of the meteorological data recorded at meteorological observatory of the Agricultural Research Station, Bagalkot.

Experimental material: Cluster bean germplasm comprising of 12 genotypes collected from different sources formed the experimental material. The experiment was laid out in a completely randomized block design with three replications. Each genotype in each replication was represented by plot size (2.00 m X 2.70 m) of six rows of 2 m length, 60 plants per treatment per replication with spacing of 45 cm X 20cm. All other crop management practices were carried out as per the package of practices of University of Horticultural Sciences, Bagalkot (Anonymous 2018).

Observations on growth, yield and quality parameters: For recording of all the growth and yield characters, six plants in each experimental plot were randomly selected avoiding border plants. Out of them, three plants were considered for vegetable purpose and three for seed purpose and they were tagged separately for taking observations on various growth and yield parameters by picking tender green pods at weekly intervals from plants tagged for vegetable purpose. Another three plants were left for seed yield parameter purpose. The seed yield and other quantitative and qualitative parameters were recorded after harvesting the fully matured pods. The observations on all growth characters were recorded by using three randomly selected tagged plants from each experimental plot and the average of the plants was computed and recorded. The germination percentage was worked out after the final germination. Plant height (cm) was measured from ground level to the tip of the plant on 90th day after sowing and recorded. Number of branches arising from the main stem was counted on 90th day after sowing and recorded. Number of days taken from the date of sowing to first flower opening was counted and recorded as days to first flowering. The days were counted from the date of sowing to the flowering of 50 per cent of the tagged plants in each experimental plot and recorded as days to 50 per cent flowering. The days were counted and recorded from the date of sowing to days at which first vegetable pod picking. The length (cm) of each selected pod was measured from the base to tip and average over ten pods was computed and recorded. The breadth (cm) of the selected pods was measured (by calipers) at the center of the pods and average over ten pods was computed. Ten fresh green vegetable pods harvested from the tagged plants selected randomly were weighed. The weight of green vegetable pods

Table 1. Growth parameters of cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] genotypes

Genotype	Germination (%)	Plant height (cm) (90 DAS)	No. of branches per plant (90 DAS)
Pusa Navabahar	90.55	86.44	0
IC-11704	90.55	51.55	5.44
RGC-1025	90	66.32	5.77
CAZG-06-1	94.44	63.22	5.88
HGS-881	61.1	77.21	6.76
AVT-II GR-4	82.22	69.33	7.33
RGC-1047	93.88	60.99	5.44
Rajendra Nagar local	78.32	75.55	0
Gujarat local	64.99	74.99	7.44
Jodhpur local	58.32	76.55	6.6
Bikaner local	81.44	66.77	6.76
Shree ram gum-1	79.88	64.88	7.03
CD (p=0.05)	20.01	11.58	1.39

harvested from the tagged plants was recorded separately. The average of all the harvests was considered as pod yield per plant per picking and expressed in grams. After four vegetable pickings, the remaining pods were left on the plant and harvested for seed purpose after maturity. The vegetable pod yield per plot was computed.

Seed yield parameters: The number of clusters produced by the tagged plants in each experimental plot was counted and average was calculated. The number of pods from tagged plants in each experimental plot was counted and average was calculated. The weight of ten dry pods randomly selected from the tagged plants was recorded. The dry pod yield was computed by adding the weight of dry pods (g) harvested in subsequent pickings from the tagged plants after maturity. The dry pods were randomly picked from tagged plants and seeds were extracted. The number of seeds was counted. The seed yield was computed by adding the weight of seeds (g) harvested from the tagged plants after maturity. One hundred seeds from each experimental plot were counted and their weight (g) was recorded.

Seed quality parameter: Gum content of endosperm of seed was estimated by adopting the methodology suggested by Association of Official Analytical Chemists (Anonymous 1958). Total nitrogen content in dry seed powder from each genotype was estimated by Micro-Kjeldahl method (Subbaiah and Asija 1956). Crude protein was calculated by multiplying the nitrogen value by 6.25 (Oser 1965). The values obtained were expressed in percentage. Crude fiber content was estimated as per standard AOAC procedure (Anonymous 2005).

Disease incidence: The per cent powdery mildew incidence was recorded as per cent leaf area infected for the genotypes which were rated from zero to four disease scale (Girish 2011).

Economics: The benefit cost ratio was worked out by the ratio of total gross returns (Rs./ha) to total cost of cultivation (Rs/ha).

Statistical analysis: Statistical analyses of experiments were performed using Web Agri Stat Package (WASP) Version 2 (Jangam and Thali 2010).

RESULTS AND DISCUSSION

Growth parameters of cluster bean genotypes: The genotypes differed significantly with respect to the different parameters like germination per cent, plant height and number of branches per plant at 90 days after sowing. The maximum per cent of germination was in CAZG-06-1 (94.44%) followed by RGC-1047 (Table 1). Plant height in Pusa Navabahar (86.44 cm) was maximum followed by HGS-881 and Jodhpur Local).,Gujarat Local recorded significantly higher number of branches per plant (7.44) followed by AVT-II GR-4 and Shreeram Gum-1 The variation in growth parameter of the cluster bean genotypes d may be attributed to their inherent genetic makeup and response to environmental condition. These results are in accordance with the results obtained by Malaghan (2012) and Rai et al (2012) in cluster bean for germination, plant height and number of branches.

Fresh pod yield of cluster bean genotypes: Significant difference was observed for number of days to first flowering, number of days to 50 per cent flowering and number of days to first vegetable pod harvest in cluster bean. The genotype Rajendra Nagar Local and Jodhpur Local took least number of days for initiation of flowering (22.00 days each) and 50 per cent of flowering (26.66 days each). Rajendra Nagar Local also required least number of days to mature (32.52 days) whereas, the genotype Bikaner Local more number of days for initiation of first flower and fifty per cent flowering (26.83 and 32.16 days, respectively). The first vegetable pod harvesting period was delayed in the genotype RGC-1025 and Bikaner Local (44.83 days each). This may be attributed to the inheritant genetic makeup and environmental factors. Significant difference was found with respect to length of the pod, pod breadth, pod weight, pod yield per plant per picking, pod yield per plot and pod yield per hectare among the genotypes (Table 2). Highest pod length and breadth was in the genotype Pusa Navabahar (11.83 cm and 0.92 cm, respectively). Highest pod weight was r in the genotype Pusa Navabahar (31.66 g) followed by Rajendra Nagar Local , IC-11704 and Gujarat Local. Apparently vegetable pod yield of some prominent genotypes were directly proportional to pod length, pod width, number of pods and pods weight. Similar observations were also been made by Girish (2011) and Malaghan (2012).

The genotype Pusa Navabahar gave the highest vegetable pod yield of 78.70 g per plant per picking. The maximum number of dry pods per plant and seed yield per plant after vegetable pod picking was recorded in CAZG-06-1 (91.33 and 31.38 g, respectively) and the maximum dry pod yield per plant after vegetable pod picking was in CAZG-06-1 (42.59 g). The difference in pod yield per plant per picking could be attributed due to the highly significant and positive relationship with the pod length (r= 0.710), pod width (r= 0.701) and pod weight (r= 0.752). These are due to genetic makeup of the genotypes and for set of environment under which these genotypes are grown.

Highest vegetable pod yield per plot (8.72 kg) and pod yield per hectare (158.72 q) were recorded by genotype CAZG-06-1 and the least in Jodhpur Local (2.45 kg, 46.14 q, respectively). Genotypes Shreeram Gum-1 (2.94 kg/plot),

AVT-II GR-4 (2.97 kg/plot), Bikaner Local (2.72 kg/plot), Gujarat Local (2.48 kg/plot) and Jodhpur Local (2.45 kg/plot) were on par with each other with respect to pod yield per plot. This difference in pod yield per plot and per hectare could be attributed due to the highly significant and positive relationship with the increase in germination per cent (r= 0.733) results in good crop standard, number of pods per cluster (r= 0.931) apart from the genetic makeup and the influence of environment. These findings are in conformity with the results of Rai et al (2012) and Ashwini et al (2019) in cluster bean.

Dry pod and seed yield of cluster bean genotypes: Significant difference was observed among the genotypes with regard to number of clusters per plant, number of pods per cluster, number of pods per plant, ten dry pods weight, dry pods yield per plant, number of seeds per dry pod, seed yield per plant and hundred seed weight (Table 3). The genotype HGS-881 recorded significantly higher number of cluster per plant (55.66). Genotype CAZG-06-1 had highest number of pods per cluster (7.69) and genotypes HGS-881 and RGC-1025 have same number of pods per cluster (3.64 each). The highest number of pods per plant was recorded in RGC-1047 (203.88) which was on par with HGS-881 (203.11). The highest number of pods per plant in these genotypes was due

Table 2. Pod yield and yield attributes of cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] genotypes

Genotypes	Pod length (cm)	Pod width (cm)	Ten fresh pod weight (g)	Pod yield/ plant per picking (g)	Duel purpose			Pod yield per plot (kg/plot)	Pod yield per ha. (q/ha)
					No. of dry pods per plant	Dry pod yield per plant (g)	Seed yield per plant (g)		
Pusa Navabahar	11.83	0.92	31.66	78.70	17.33	8.87	5.50	4.93	91.35
IC-11704	10.63	0.86	25.66	48.24	59.00	33.97	25.31	7.55	138.82
RGC-1025	7.96	0.76	17.66	24.87	39.00	20.68	16.43	4.03	74.63
CAZG-06-1	7.90	0.76	17.50	52.99	91.33	42.59	31.38	8.72	158.72
HGS-881	7.57	0.75	14.66	50.92	41.33	25.82	18.59	3.10	56.26
AVT-II GR-4	5.61	0.72	9.83	24.04	32.66	21.84	16.27	2.97	53.51
RGC-1047	7.24	0.81	16.16	39.93	77.33	34.16	26.05	6.76	127.43
Rajendra Nagar local	10.40	0.92	26.16	63.81	12.66	5.57	3.37	4.13	78.15
Gujarat local	8.83	0.84	22.00	67.02	57.00	35.98	22.13	2.48	46.91
Jodhpur local	6.69	0.72	14.83	54.81	38.66	22.97	15.89	2.45	46.14
Bikaner local	6.79	0.72	14.16	34.04	66.00	30.83	23.04	2.72	51.35
Shree ram gum-1	6.21	0.73	13.16	43.88	68.00	32.43	25.51	2.94	55.29
CD (p=0.05)	1.49*	0.10*	4.25*	12.70*	7.17*	2.78*	2.32*	1.11*	20.82*

Table 3. Seed yield and yield attributes of cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] genotypes

Genotypes	Number of cluster/plant	Number of pods/cluster	Number of pods/plant	Ten dry pod weight (g)	Dry pod yield per plant (g)	Number of seeds per dry pod	Seed yield per plant (g)	Hundred seed weight (g)
PusaNavabahar	28.55	2.06	59.55	7.44	21.66	6.77	13.00	3.52
IC-11704	21.66	2.81	59.77	5.88	25.77	7.23	26.83	3.41
RGC-1025	26.55	3.64	96.88	3.55	24.33	6.14	41.33	3.24
CAZG-06-1	17.66	7.69	133.66	5.84	52.66	7.90	53.61	3.91
HGS-881	55.66	3.64	203.11	3.33	52.55	6.33	34.16	3.35
AVT-II GR-4	39.22	2.28	89.26	3.88	23.77	6.91	41.00	3.52
RGC-1047	34.22	5.96	203.88	6.92	51.00	8.14	41.72	3.98
Madhuri	14.88	5.55	82.11	7.10	16.33	5.69	19.83	3.39
Gujarath local	52.00	4.07	152.33	3.33	48.55	7.12	28.66	3.17
Jodhpur local	40.77	2.99	121.88	3.55	41.77	7.18	27.16	3.17
Bikenar local	30.11	3.5	85.18	3.77	40.44	7.15	26.66	3.12
Shree ram gum-1	32.00	4.42	140.88	4.00	49.21	7.08	24.33	3.18
CD (p=0.05)	9.67*	1.70*	30.15*	0.93*	9.32*	0.74*	8.50*	0.33

to higher number of cluster per plant and higher number of pods per cluster. The significant difference in these genotypes for number of cluster per plant, number of pods per cluster and number of pods per plant may be due to genetic and environmental factors. The highest number of pods per plant in the genotypes RGC-1047 and HGS-881 is due to direct inter-relationship between number of cluster per plant and number of pods per cluster. These results are in conformity with earlier works of Malaghan (2012) and Rai et al (2012) in cluster bean.

Highest ten dry pods weight was observed in the cluster bean genotype Pusa Navabahar (7.44 g) and genotypes RGC-1025 and Jodhpur Local were on par with each other with dry pods weight of 3.55 g each. The dry pod yield per plant was significantly higher in CAZG-06-1 (52.66 g). The significant differences among the genotypes may be attributed to variation in number of branches, number of pods per plant and number of seeds per pod. Similar observations were made by Girish (2011) and Malaghan (2012) in cluster bean.

The genotype RGC-1047 had the highest number of seeds per pod (8.14). This may be due to higher dry pod yield per plant in these genotypes. Significantly highest seed yield was recorded in genotype CAZG-06-1 (53.61 g). Genotypes RGC-1047, RGC-1025 and AVT-II GR-4 were on par with each other and the remaining genotypes were significant from these genotypes. Significantly higher seed yield in CAZG-06-1 may be due to more number of pods per cluster, dry pod yield per plant and more number of seeds per dry pod as observed in the present study. The genotype CAZG-06-1 recorded significantly higher seed weight (3.98 g) for 100 seed weight. Higher seed weight had also contributed for higher seed yield per plant. The superiority of CAZG-06-1 over other genotypes with respect to seed yield components *viz.*, dry pod yield, seed yield per plant and hundred seed weight may be due to its genetic potentiality to utilize the growth resources and translocate photosynthates from source to sink.

Quality parameters of cluster bean genotypes: Significant difference was observed for gum content, protein content and fibre content (Table 4). Highest gum content was recorded in genotype CAZG-06-1. THe highest protein content was noticed the genotype Rajendra Nagar Local and no significant difference was observed among these genotypes. Cluster bean genotype IC-11704 recorded highest crude fibre content, whereas the least was found in AVT-II GR-4. The significant difference in the quality parameters of the genotypes may be attributed to difference in number of seeds per plant, seed yield per plant, 100 seed weight, number of dry pods per plant and dry pod yield per plant due to specific genetical traits.

Incidence of powdery mildew disease in cluster bean genotypes: The powdery mildew disease incidence was severe in Pusa Navabahar and Rajendra Nagar Local due to larger leaf area and absence of pubescence characters which are associated with favorable environment condition while remaining genotypes were shown moderately susceptible.

Correlation studies: Correlation coefficients worked out for yield, quality and seed parameters in cluster bean (Table 5). Pod length had highly significant positive correlation with

Table 4. Quality parameters and powdery mildew disease incidence of cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] genotypes

Genotypes	Gum content (%)	Protein content (%)	Fibre content (%)	Per cent leaf area infected	Disease score (0-4 scale)	Disease reaction
Pusa Navabahar	27.46	25.08	4.66	76.41 (60.92)	4	Susceptible
IC-11704	26.73	28.00	9.90	52.14 (46.21)	3	Moderately susceptible
RGC-1025	28.56	28.58	7.43	61.23 (51.47)	3	Moderately susceptible
CAZG-06-1	32.86	32.66	5.46	53.45 (46.96)	3	Moderately susceptible
HGS-881	25.90	35.58	4.43	68.47 (55.82)	3	Moderately susceptible
AVT-II GR-4	23.20	36.75	4.10	65.32 (53.90)	3	Moderately susceptible
RGC-1047	32.33	35.58	8.10	50.67 (45.37)	3	Moderately susceptible
Rajendra Nagar local	13.20	38.33	4.13	78.57 (62.40)	4	Susceptible
Gujarath local	25.70	25.66	5.66	59.78 (50.62)	3	Moderately susceptible
Jodhpur local	22.36	25.61	9.80	67.48 (55.21)	3	Moderately susceptible
Bikenar local	24.80	30.33	8.26	60.32 (50.94)	3	Moderately susceptible
Shree ram gum-1	31.66	26.83	8.16	62.37 (52.14)	3	Moderately susceptible
CD @ 1%	8.52**	4.95**	2.68**	-	-	-

Table 5. Correlation coefficients among the different growth, yield, quality and seed components in cluster bean genotypes

@	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1	-0.5	-0.308	0.278	0.307	0.16	0.253	0.253	0.245	-0.231	0.733**	0.737**	-0.33	0.58*	-0.724**	0.307	0.276	-0.282	0.618*	0.614*	0.444	0.120	0.043
2		1	-0.420	-0.318	-0.443	-0.443	0.222	0.233	0.263	0.570	-0.540	-0.542	-0.012	-0.283	0.368	-0.467	-0.472	-0.146	-0.017	-0.255	-0.408	-0.113	-0.569
3			1	0.324	0.387	0.453	-0.785**	-0.825**	-0.799**	-0.587*	-0.239	-0.250	0.450	-0.436	0.548	0.416	0.584*	0.621*	-0.807**	-0.209	0.411	-0.112	0.364
4				1	0.938**	0.890**	-0.341	-0.555	-0.374	-0.659*	-0.056	-0.066	-0.393	-0.296	-0.140	0.088	0.141	-0.167	-0.327	-0.218	0.247	-0.203	0.435
5					1	0.946**	-0.375	-0.594*	-0.405	-0.679*	-0.023	-0.033	-0.328	-0.274	-0.222	0.066	0.181	-0.063	-0.383	-0.280	0.357	-0.263	0.496
6						1	-0.379	-0.622*	-0.400	-0.628*	-0.040	-0.048	-0.285	-0.269	-0.183	0.098	0.218	0.006	-0.468	-0.352	0.286	-0.346	0.632*
7							1	0.928**	0.988**	0.710**	0.374	0.381	-0.454	0.598*	-0.386	-0.292	-0.519	-0.503	0.658*	0.088	-0.235	-0.204	-0.189
8								1	0.939**	0.701*	0.324	0.337	-0.326	0.555	-0.354	-0.262	-0.516	-0.493	0.755**	0.197	-0.314	-0.020	-0.288
9									1	0.752**	0.335	0.344	-0.461	0.580*	-0.389	-0.251	-0.564	-0.490	0.671*	0.070	-0.227	-0.277	-0.159
10										1	0.086	0.092	-0.058	0.442	0.006	-0.088	-0.566	-0.011	0.450	0.016	-0.210	-0.311	-0.270
11											1	0.999**	-0.040	0.931**	-0.598*	0.486	0.414	0.033	0.665*	0.791**	0.440	0.158	0.101
12												1	-0.036	0.933**	-0.604*	0.489	0.401	0.033	0.679*	0.792**	0.437	0.157	0.113
13													1	-0.053	0.595*	0.333	0.428	0.830**	-0.242	0.268	0.392	0.257	-0.041
14														1	-0.541	0.409	0.158	0.025	0.773**	0.719**	0.317	0.030	0.004
15															1	0.027	0.006	0.486	-0.640*	-0.306	0.064	-0.112	-0.112
16																1	0.621*	0.605*	0.125	0.534	0.687*	-0.160	0.422
17																	1	0.594*	-0.203	0.706*	0.579*	0.396	-0.046
18																		1	-0.345	0.151	0.583*	-0.068	0.194
19																			1	0.653*	-0.034	0.224	-0.165
20																				1	0.401	0.475	-0.228
21																					1	-0.309	0.292
22																						1	-0.497
23																							1

Critical r-1%= 0.708 5%= 0.576 * and ** indicate significance at p=0.05 and p=0.01 respectively

@:Characters; 1: Germination; 2: Plant height; 3: No. of branches; 4: Days to first flowering; 5: Days to fifty % flowering; 6: Days to first harvest; 7: Pod length; 8: Pod width; 9: Pod weight; 10: Pod yield /plant/picking; 11: Pod yield /plot; 12: Pod yield/ ha; 13: No. of dry pods/ plant; 14: No. of pods/cluster; 15: No. of cluster/plant; 16: No. of seeds /pod; 17: Seed yield/plant; 18: Dry pod yield/plant; 19: Ten dry pod weight; 20: 100 seed weight; 21: Gum content 22: Protein content; 23: Fibre content

Table 6. Economics for different cluster bean genotypes

Genotypes	Total yield (t/ha)	Total gross returns (Rs)	Net returns (Rs)	B: C ratio
Pusa Navabahar	9.13	182600	137737	4.07
IC-11704	13.88	277600	232737	6.18
RGC-1025	7.46	149200	104337	3.32
CAZG-06-1	15.87	317400	272537	7.07
HGS-881	5.62	112400	67537	2.50
AVT-II GR-1	5.35	106400	61537	2.37
RGC-1047	12.74	254800	209937	5.67
Rajendra Nagar local	7.81	156200	111337	3.48
Gujarath local	4.69	93800	48937	2.09
Jodhpur local	4.61	92200	47337	2.05
Bikenar local	5.13	102600	57737	2.28
Shree ram gum-1	5.52	110400	65637	2.46

Total cost of cultivation: Rs. 44862.25

pod width, pod weight and pod yield per plant per picking, number of pods per cluster, ten dry pods weight). Pod width was significantly and positively correlated with pod weight, ten dry pod weight and pod yield per plant per picking. Highly significant and positive relationship was observed with pod weight and pod yield per plant per picking, number of pods per cluster and ten dry pod weight. Pod yield per plot was highly significant and positive relationship with pod yield per hectare, number of pods per cluster, 100 seed weight and ten dry pods weight and had significant negative relationship with number of cluster per plant. Pod yield per hectare had highly significant and positive correlation with number of pod per cluster, 100 seed weight and ten dry pods weight and it had significant and negative correlation with number of cluster per plant. Number of dry pods per plant was highly significant and positively correlated with number of cluster per plant and dry pod yield per plant. Number of pods per cluster was highly significant and positively correlated with ten dry pod weight, 100 seed weight. Number of cluster per plant was significant and negatively correlated with ten dry pod weight. Ten dry pod weight was highly significant and positive relationship with 100 seed weight. Number of seeds per pod was significant and positively correlated with dry pod yield per plant and guar gum content. Seed yield per plant was having significant positive relationship with dry pod yield per plant, 100 seed weight and gum content.

Economics: The highest net profit was obtained from CAZG-06-1 genotype (Rs 2,72,537.75) followed by IC-11704, RGC-1047, RGC-1025 and PusaNavabahar (Table 6).

CONCLUSION

Genotypes CAZG-06-1, IC-11704 and RGC-1047 are superior prefers more with respect to gum content, vegetable pod yield, seed yield and dual purpose and these can be recommended for commercial cultivation under Northern Dry Zone of Karnataka during *Rabi* season. While Rajendra Nagar Local, AVT-II GR-4 and HGS-881 have maximum protein content and can recommended them for fodder purpose

AUTHORS CONTRIBUTION

Dr. Vasant M. Ganiger collected the germplasm from different parts of India and initiated the breeding work according to objectives. Further, continued the work intensively. Gangadhar T. C. part of the M.Sc. work carried out the experiment as per the programme of research. Dr. Bhuvaneshwari G advised with regard to quality parameters. Dr. Vijay Kumar Narayanpur and Dr. Shankrappa T.H. have given technical guidance for writing the manuscript. Dr. Shruthi P. Gondi assisted for carrying the experiment and statistical analysis.

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Sustainable Production of Tomato (*Solanum lycopersicum* L.) through Intercropping

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***Abstract*:** The present study was undertaken during 2021-22 to observe the effect of intercropping on tomato with nine treatments. Four intercrops were sown with tomato in 1:1 proportion. Tomato + fenugreek intercropping system recorded significantly maximum values for all the growth attributes like plant height (60.62 cm), number of branches per plant (9.65) and leaf no/plant (118.17) and yield attribute like tomato equivalent yield (80.76 t/ha). Perusal of data on quality parameter also showed similar trend as highest TSS, ascorbic acid, lycopene content of tomato fruit were observed in tomato + fenugreek intercropping model (6.87°Brix, 25.77 mg/100g 3.98 mg/100g respectively).The treatment tomato + spinach recorded minimum TSS was 4°Brix,24.09 mg/100g and 2.75 mg/100g for, ascorbic acid, lycopene content respectively. Enumeration of economic of cultivation of the trial revealed that tomato + fenugreek model recorded maximum B:C ratio (3.17) and minimum in tomato + spinach treatment (2.56). Considering the findings it may be concluded that inclusion of fenugreek with tomato can be a profitable and sustainable production system for the farmers of Gangetic plains of West Bengal.

***Keywords*:** Intercropping, *Solanum lycopersicum* L, Fenugreek

Tomato (*Solanum lycopersicum* L) belonging to the family Solanaceae is one of the most important fruit vegetables grown throughout the world. Tomato is universally treated as a "Protective Food" as it is packed several nutrients (Kichu et al 2022) and is also a very good source of income to small and marginal farmers. India produced 19.07 million tonnes tomato from an area of 7.81 million (NHB 2020). Tomato fruit is packed with minerals, vitamins, proteins, essential amino acids like leucine, threonine, valine, histidine, lysine and arginine (Ali et al 2021). Massive growth rate of population has decreased per capita holding size in India at an alarming rate. On the other hand, degradation of soil fertility, natural hazards, pest and disease incidences, market price fluctuation put to the farming families in insecurity of income generation for their livelihood. Hence, intensive cultivation and effective utilization of land resources is demanded by the prevalent situation. Among different cropping system intercropping is the most suitable practice to stabilize the production (Kabiraj et al 2017) and two or many crops can be grown at a time from the same land having huge advantages over mono cropping (Islam et al 2021). Intercropping with vegetables is also profitable as it generates more income of the farm through increased production unit^{-1} area from a greater number of crops in a season of a year (Dodiya et al 2018) as it provides complete and economical use of natural resources like soil, water, space, nutrients and sunlight (Qinyu et al 2022) through selection of crop combination of different duration and rooting pattern. Intercropping is mostly practiced by poor or marginal farmers of many tropical parts of the world (Bitew and Abera 2018). Tomato is one of the important cash earning crops for the vegetable growers of this zone in Gangetic plains of West Bengal tomato is cultivated with great care. Farmers of this zone sometimes apply indiscriminate fertilizers or plant protection chemicals which have ultimately degraded the soil structure and texture. On the other hand prevalence of early and late blight due to unusual environmental conditions makes havoc for the crop and the farmers face tremendous crop loss.

So mono cropping of tomato cannot address these problems. The tomato is grown with wider spacing which offers ample scope for taking intercrops in between Intercropping with some companion plants could increase tomato quality, suppress nematodes, and improve soil environment without decreasing tomato yield. Keeping all these present study was undertaken.

MATERIAL AND METHODS

This experiment was carried out at Bidhan Chandra Krishi Vishwavidyalaya, Kalyani, Nadia, during *rabi* season of the year 2021-22. The location of the experimental site is 23.5^0 North latitude and 80^0 East longitudes with average altitude of 9.75 m above the MSL. The experimental soil contained 0.65% organic carbon, 186.19 kg/ha available

nitrogen, 57.20 kg/ha available P and 136.70 kg/ha available K.

The research work was conducted in the randomized block design with nine) treatment combinations and replicated thrice. The treatments combinations were T_1-Sole Tomato; T_2-Sole Cabbage; T_3-Sole Radish; T_4-Sole Fenugreek; T_5-Sole Spinach; T_6-Tomato + Cabbage; T_7-Tomato + Radish; T_8-Tomato + Fenugreek; T_9-Tomato + Spinach. Forty five days old PAN 1286 variety of tomato seedlings were transplanted in the individual plots measuring 7.5 square meter area with a spacing of 60 cm x 50 cm. Seeds of the intercrops were sown in between the rows of tomato in 1:1 ratio i.e. in additive series and received same inputs as in case of tomato. Forty-five days old cabbage seedlings were transplanted with a spacing of 50 cm x 50 cm whereas other intercrops like fenugreek, radish and spinach were grown as sole crop at spacing of 20 cm x 10 cm each. Sole main and intercrops were raised and suitable measures and methods were adopted for fertilizer application, weed minimization, harvesting, disease and pest control following standard cultivation practices. Observations were on plant height (cm), number of branches plant^{-1}, number of leaves plant^{-1}, number of fruitsplant^{-1}, fruit yield plant^{-1} (kg), fruit yield plot^{-1} (kg), yield ha^{-1} (ton) and tomato equivalent yield ha^{-1} (ton). Biochemical parameters Total soluble solids (TSS) content was estimated with the help of a digital refractometer (0 to 32°Brix), ascorbic acid and lycopene content of ripe tomato fruits were estimated (Ranganna 1986). In association of crop yield, tomato Equivalent Yield (CEY) (Verma and Modgal 1983), land equivalent ratio (LER) (Mead and Willey 1980), aggressivity (A) (McGilchrist 1965) and relative crowding coefficient (K) (Hall 1974) were measured.

Tomato equivalent yield: This was measured as:

$$\text{Yield of tomato in intercrop} + \frac{\text{Yield of intercrop in a mixed stand x price of intercrop}}{\text{Price of tomato}}$$

LER = ∑ Yij/Yii,

Where, Yij = yield of crop in intercropping system, Yii = yield of the crop in sole cropping system.

Aggressivity (A) : This was estimated as

$$Aab = \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times Zba}$$

Where, Aab = Aggressivity value for the component crop "a".

Relative crowding coefficient (K):

$$Kab = \frac{Y_{ab} \text{ X } Z_{ba}}{(Y_{aa}\text{-}Y_{ab}) \text{ x } Z_{ab}}$$ (a and b are two crops in intercropping system)

Where, Yab= yield of crop a in mixed stand, Yaa= yield of crop a in pure stand, Zab= sown proportion of crop a (in mixed stand with b), Zba= sown proportion of crop b (in mixed stand with crop a. Mean values of each entry in each replication for all the traits were subjected to statistical analysis by using MS Office Excel software.

Economics of tomato production under intercropping system was calculated by computing the market price of tomato and their intercrops and net returns and benefit cost ratios were worked out for each treatment (Zivenge et al 2013).

Net returns = Gross returns – Total production cost.

Benefit: Cost = Gross returns / Total production cost

RESULTS AND DISCUSSION

Growth parameters: Intercropping had significantly affected most of the growth parameters of tomato (Table 1). Tomato intercropped with fenugreek recorded significantly maximum values for plant height (60.62 cm), number of leaves and branches plant-1 (118.17 and 9.65 respectively) over all other treatments under study except with sole tomato where it was significantly *at par*. Among different intercropping combinations, higher values for all these growth attributes were observed with tomato + fenugreek intercropping system which might be due to better utilization of resources and less competition between both the component crops for different horizontal and vertical resources like solar radiation, moisture, nutrients, etc. compared to other intercropping treatments (Kichu et al 2022). The tomato + fenugreek model recorded maximum land equivalent ratio, Relative crowding coefficient and minimum aggressivity, tomato, the main crop faced least competition for the biological resources with fenugreek resulting tallest plant, maximum number of leaves and branches. Fenugreek, being a legume vegetable can fix ample amount nitrogen and this phenomenon might have encouraged plant growth and branching process. Similar observation with higher values of growth attributing characters of tomato was observed when tomato was intercropped with another legume vegetable like common bean (Abd El-Gaid et al 2014).

Yield parameters: Maximum values for number of fruits plant^{-1}(20.23), yield plant^{-1} (2.05kg), yield plot^{-1} (61.15kg), yield ha^{-1} (77.53 ton/ha) and tomato equivalent yield (80.76 ton/ha) were observed in tomato + fenugreek intercropping system (Table 1). In all the cases tomato + spinach model recorded minimum values for yield attributing characters. Intercropping tomato with legume i.e. fenugreek might have influenced the performance of component crops and improved residual nitrogen contribution to the cropping

systems (Nwofia et al 2017), thus produced a high degree of complimentary effect. The maximum tomato equivalent yield in tomato + fenugreek intercropping might be due to higher yield of the main crop and greater market price of component crop.

Quality parameters: Biochemical parameters of tomato was also influenced by intercropping of different short duration vegetable crops (Table 2). Tomato intercropped with Fenugreek (T_8) recorded significantly maximum TSS (6.87°Brix), ascorbic acid content (25.77 mg) and lycopene content (3.98) content over all other treatments. This might be due to lesser competition between tomato and fenugreek resulting additional uptake of nutrients by the main crop and less uptake of nutrients by intercrops. The higher values of ascorbic acid content was in tomato and fenugreek intercropping and sole cropping of tomato may be attributed to increase the availability of nutrients in the soil that might lead to synthesis and accumulation of more photosynthates which could have mobilized the biosynthesis of ascorbic acid.

Competitive Function

Land equivalent ratio: Data regarding competitive functions also varied due to intercropping (Table 2). Tomato + fenugreek intercropping gave the highest LER (1.92). Highest value of LER with tomato + fenugreek intercropping system might be due to efficient utilization of natural resources viz., space, light, and on other hand symbiotic relationship between tomato and fenugreek was compatible due to differential rooting pattern of the two crops along with advantage of biological nitrogen fixation from a component crop. Nwofia et al (2017) recorded highest value of LER in cowpea + eggplant intercropping system.

Aggressivity: Experimental results showed that tomato grown with fenugreek was least aggressive (-6.60) preceded by tomato+ cabbage (-0.05). Tomato grown with spinach and radish was most aggressive (-0.04) than all of the intercropping. Tomato + spinach and tomato + radish intercropping system were most competitive than all other combinations and increased the power of dominance of tomato and thereby led to the maximum aggressivity value for this systems. The fenugreek and cabbage were most compatible with minimum aggressivity for growing with tomato.

Relative crowding coefficient: Relative crowding coefficient of intercropping was greater than one for all the treatments which indicated that it was advantageous for yield and land utilization efficiency over monocropping. Tomato + fenugreek system recorded maximum value for this parameter (4.33) followed by tomato + cabbage (3.91) and tomato + radish (3.88) systems of intercropping. Minimum value was obtained from tomato + spinach intercropping system (3.19). This result was in conformity with Seran and Brintha (2009) on capsicum based intercropping system and highest value (28.18) for relative crowding coefficient (RCC) was recorded when 30/60 cm paired row planting of capsicum was done in one row of vegetable cowpea.

Table 1. Effect of intercropping on growth and yield parameters of tomato

Treatments	Plant height (cm)	No. of leaves plant^{-1}	Number of branches plant^{-1}	Number of fruits plant^{-1}	Yield plant $^{-1}$ (kg)	Yield plot^{-1} (kg)	Yield ha^{-1} (ton)	Tomato equivalent yield ha^{-1} (t)
T1	54.96	111.53	8.04	19.14	1.88	52.59	70.12	70.12
T6	41.74	87.31	7.50	14.93	1.53	47.00	65.50	72.65
T7	41.16	82.47	6.47	11.04	1.21	45.00	59.35	67.63
T8	60.62	118.17	9.65	20.23	2.05	61.15	77.53	80.76
T9	40.43	68.42	5.80	9.33	1.10	43.00	56.10	62.77
CD (p =0.05)	14.64	13.17	1.80	5.41	0.37	5.07	7.33	7.76

Table 2. Effect of intercropping on quality parameters and competitive functions of tomato

Treatments	TSS content (°Brix)	Ascorbic acid (mg/100g)	Lycopene (mg/100g)	Land equivalent ratio	Aggressivity	Relative crowding coefficient
T1	6.30	25.65	3.85	1.00	-	-
T6	5.63	25.30	3.63	1.80	-0.05	3.91
T7	4.97	24.26	3.20	1.65	-0.04	3.88
T8	6.87	25.77	3.98	1.92	-6.60	4.33
T9	4.00	24.09	2.75	1.56	-0.04	3.19
CD (p =0.05)	0.34	1.27	0.51	-	-	-

Table 3 .Economics of tomato based intercropping system

Treatments	Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	Benefit: Cost ratio
T1	136642	385660	249018	2.82
T2	21642	49360	27718	2.28
T3	27272	58426	31154	2.14
T4	10628	21840	11212	2.05
T5	22642	48180	25538	2.13
T6	140642	383866	243224	2.73
T7	148642	402966.67	254324.67	2.71
T8	147224	466199.99	318975.99	3.17
T9	137242	351999.99	214757.99	2.56

Economics of production: Tomato + fenugreek intercropping system was most remunerative as it recorded the highest gross return and B:C ratio (Rs. 466199 and 3.17, respectively). Among different combinations, tomato grown with fenugreek was most remunerative which might be due to maximum yield of tomato and comparatively lower cost of cultivation than all other treatments. Thapa (2015) also found that the intercropping system garlic + garden pea combination was the most economical.

CONCLUSION

Cultivation of fenugreek as an intercrop with tomato is can be a profitable venture as this system recorded highest yield as well as highest return through efficient utilization of land, water and light. Moreover intercropping with fenugreek, improves the nutritional quality of tomato with respect to increased amount of ascorbic acid TSS and lycopene content. Thus it may be concluded that intercropping of fenugreek with tomato can be adopted as sustainable and viable production system for the farmers of Gangetic plains of West Bengal.

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Off-Season and Quality Production of Watermelon by Modifying Micro-Climate under Hot Arid Conditions

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***Abstract*:** The field experiment was conducted to standardize the sowing date and covering material for off-season and quality production of watermelon. Under different sowing dates and covering material, watermelon took 54-62 and 83-91 days after sowing for first female flower and first marketable harvest, respectively. The treatment 10th January with polythene sheet recorded the highest number of days for last harvest followed by 10th January with non-woven cloth, while the least number of days for last harvest was in treatment 10th February under open field condition. The crop raised on 20th December with non-woven cloth attained the harvestable maturity on 19th March *i.e.* 52 days earlier as compared to 10th May under open filed sowing (10th February). The sowing under treatment 10th January with polythene sheet recorded the highest yield (256.32 q/ha) as well as fruiting duration, while the lowest yield (156.78 q/ha) was with the treatment 10th February under open condition. Thus, an advancement of 40-50 days was achieved by modifying the micro-climate during winter under tunnel which ultimately fetches higher price in the market as compared to normal season sowing.

***Keywords*:** *Citrullus lanatus*, Covering material, Early harvest, Low tunnels, Micro-climate

Indian arid zone covers a large area and contribute for one of the largest subtropical deserts of the globe. Hot arid zone is distributed in more than 31.7 million ha area which mainly covers the states of Rajasthan, Gujarat, Karnataka, Andhra Pradesh, Haryana and Punjab. Western Rajasthan leads the area of hot arid region covering 19.62 m ha area followed by North-western Gujarat covering 2.16 m ha. This region is known for many constraints such as high aridity index, extremes of temperature (ranging from 0 to 48°C), low and erratic rainfall, high wind velocity and dust storm, high soil pH, less water holding capacity, limited availability of groundwater with saline in nature (More 2010). In spite of these constraints, the hot arid region of the country has ample scope for cultivation of cucurbitaceous crops like watermelon, muskmelon, bottle gourd, ridge gourd, long melon, tinda, summer squash. The cucurbitaceous crops are generally sown during second-third week of February for summer season crop. The flowering stage of this season crop concurs with the prevailing high temperature and *Loo* (hot wind) which lead to high transpiration rate causing wilting of plants. Further, the soil of this region gets warm soon because of its sandy texture, which causes burning of female (pistillate) flowers touching the soil. The honey bee population which is a major pollinator of the cucurbits is also decreased to a large extent during summer season which affects fruit setting and thereby yield. High temperature is known to lower sex ratio in cucurbits by inducing higher number of staminate flowers than the pistillate flowers which again becomes a contributing factor for low yield with poor quality produce (Choudhary et al 2018). These vegetables are over flooded in the markets during their main season (April onwards) which causes glut in the market which ultimately results in very low economic return to the farmers. Sometimes the farmers are even not able to get back the cost of cultivation invested for growing these vegetables. But the same vegetables if grown early (during February-March), get very high prices as compared to normal season harvest in different corners of the country. The demand of early and off-season produce is increasing at faster rate because of shifting of choice of consumers for off season and high quality produce as well as continuous increase in availability of such produce. For production of cucurbitaceous vegetables during off-season, river bed cultivation has been and still is in practice, despite the limitation of area availability and its further extension under this practice. Protected cultivation technologies have specific advantages over open field cultivation practices which include protection against both biotic and abiotic stress factors (Singh and Sirohi 2006). But, the economics of protected cultivation is an important factor because it involves very high initial and running cost. Therefore, it becomes important to create protected structures which have low cost involvement so that maximum benefit against per unit of area and cost invested can be ensured (Choudhary and Verma 2018). The adoption of low cost protected structures like low tunnels with some modification as per local agro-climate may become a viable

option for early and off-season harvest of cucurbits in arid regions (Choudhary et al 2015). The technology has wide scope in arid regions and is gaining popularity among the stakeholders however, it lacks the information on use of covering material, availability of low tunnel responsive varieties and complete package of practice. Thus, there is a need to standardize tunnel technology for particular crop along with the use of non-woven cloth for tunnel preparation. Keeping the above facts in view, an experiment on low tunnel cultivation of watermelon was taken up to standardize the sowing date and covering material for off-season and quality harvest of watermelon (*Citrullus lanatus*) under hot arid conditions.

MATERIAL AND METHODS

The field experiment was conducted at research farm of ICAR-Central Institute for Arid Horticulture, Bikaner, Rajasthan during 2018-19 and 2019-20. It is located at 28°N latitude, 73° 18°E longitude at an altitude of 234.84 m above sea level. Watermelon var. 'AHW/BR-40' developed by ICAR-CIAH, Bikaner was taken for the experiment. The experiment was undertaken in randomized block design in three replications with seven treatments (Table 2). The used covering material *i.e.* biodegradable transparent polythene sheet and non-woven cloth were of 25 micron and 25 gsm, respectively. Before construction of low tunnels, the land was brought into a fine tilth by ploughing it 2-3 times. About 45-60 cm wide and 45-50 cm deep trenches were prepared at a distance of 2.0 m in east-west direction. Recommended doses of manure (FYM) and fertilizers (NPK) were applied in trenches and mixed well in the soil (Choudhary and Verma 2018). As low tunnel cultivation is a new practice, the care has to be taken in its construction. For irrigation and fertigation, one lateral (12-16 mm size) was laid down in each trench which has drippers at 60 cm distance with 4 litre/ hour water discharge rate. For construction of low tunnel, the flexible galvanized iron hoops of 4-6 mm thickness were used and 3-4 m distance was kept between two hoops on trenches. The hoops were placed in such a way that width of two ends of hoop and maximum height of the hoop not to go beyond 1.0 m. Before sowing, the seeds were treated with Vitavax @ 2 g/ kg seed followed by wrapping in gunny bag and keeping at warm place for 2-3 days to facilitate quick germination. The trenches were irrigated with drip irrigation prior to sowing. Two seeds near each dripper were sown at the spacing of 2.0 m (row-row) × 0.6 m (plant-plant) to maintain optimum plant density. The trenches were covered with the help of covering materials over the hoops (Fig. 1). The weather parameters including temperature and relative humidity (RH) during crop duration (December-May) of both the seasons (Table 1) and average temperature profile inside and outside the tunnel were also recorded (Fig. 2). The covering material was removed during second week of February after gradual hardening of the plants. Initially the covering was removed during day time and again covered during night time for continuously 2-3 days followed by

Table 1. Meteorological data of winter spring seasons of 2018-19 and 2019-20 under open field conditions at experimental location

Month	Temperature (°C)		RH		Total rainfall (mm)	Wind speed (kmph)	Evaporation (mm/day)	BSSH
	Maximum	Minimum	RH1	RH2				
November, 2018	30.6	11.4	69.6	27.4	0.8	2.86	3.7	8.7
December, 2018	24.7	5.0	75.3	31.7	0.0	2.8	3.0	8.6
January, 2019	22.1	5.9	85.3	36.8	2.7	3.5	2.8	6.6
February, 2019	23.5	7.8	82.9	38.3	0.0	4.9	3.8	7.4
March, 2019	30.5	13.1	69.8	34.1	1.8	5.2	5.6	6.9
April, 2019	39.6	22.6	87.6	76.6	31	6.1	9.9	3.2
May, 2019	41.4	25.4	72.2	53.5	09	7.4	12.2	10.6
November, 2019	27.1	12.8	84.2	48.6	27.2	3.5	7.8	6.0
December, 2019	20.9	5.0	86.8	45.1	6.8	3.1	6.2	7.0
January, 2020	20.0	5.1	85.9	49.3	21.8	3.8	6.5	6.7
February, 2020	27.0	8.0	76.6	31.3	0.0	4.1	9.6	9.4
March, 2020	29.6	14.1	73.4	32.3	29.8	6.1	5.0	7.3
April, 2020	37.3	21.0	58.5	26.9	7.0	6.4	9.1	9.2
May, 2020	42.3	25.2	55.3	26.0	29.4	8.2	11.3	0.3

complete removal of the covering (Fig. 1). The five plants were selected randomly in each treatment for recording various plant growth and yield parameters. The data were recorded on days to first male flower, first female flower, first harvest, last harvest, fruiting duration, fruit diameter (cm), fruits per plant and fruit yield (q/ha). The quality parameters on fruit cracking were also recorded. The pooled data of both the years were analyzed statistically using OP Stat software (Sheoran et al 1998).

RESULTS AND DISCUSSION

Weather parameters: The average outside daily maximum air temperature was 24.7°C, 22.1°C and 23.5°C whereas, the average daily minimum air temperature was 5.0°C, 5.9 and 7.8°C in December, 2018, January and February, 2019, respectively. Similarly, the average outside daily maximum and minimum air temperature was low (Table 1). From the weather parameter, it is clear that any cucurbit cannot be grown during winter (December-January) due to low temperature (5-9 °C) under open field in North-Indian plains. But, with the use of low tunnel, it was made possible to grow the watermelon by modifying the micro-climate as per requirement of the crop. The air temperature inside the tunnel was 6-10 °C higher than the outside (Fig. 2) which creates the favourable micro-climate required by the crop during winter itself for early season harvest. These temperature differences were because covering material of tunnels retained an increased amount of heat radiating from both, the soil and the plants (Ibarra et al 2001).

Fig. 1. A general field view of the experiment

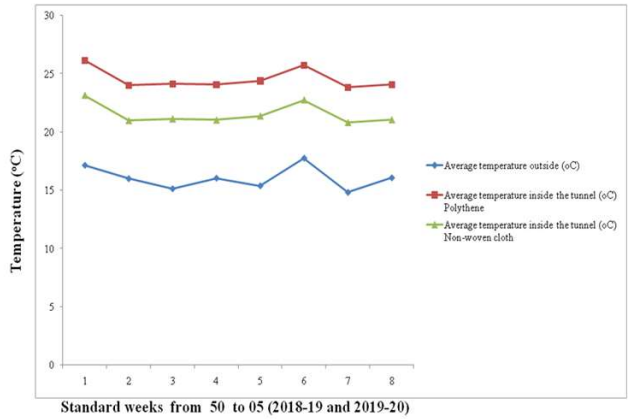

Fig. 2. Average temperature profile inside and outside the tunnel

Flower attributing parameters: Under different dates of sowing and covering material it took 7-15 days after sowing for 50% germination. Germination was earlier in biodegradable plastic sheet of 25 micron than non-woven cloth (25 gsm) because the temperature inside the tunnel with polythene cover was comparatively higher than the non-woven cloth. The temperature differences between the coverings might be due to more retention of an increased amount of heat by polythene covering as compared to non-woven cloth. Plant growth inside the tunnels was also better as compared to open field condition. This might be due to the presence of favourable soil and air temperature which is associated with increased plant establishment and growth (Both et al 2007). Under different treatments days to first male flower exhibited a range of 49-57 days (Table 2, Fig. 3). Earliest flowering (49 days) was in T6 followed by T5 and T7 while T2 took maximum days (57) for first male flowering. Early flowering might be correlated with optimum temperature and relative humidity at early sowing during winter under low tunnels which boosted the germination process as well as vigorous growth of seedlings. Covering with biodegradable plastic sheet of 25 micron recorded male flowers earlier than non-woven cloth (25 gsm) because the temperature inside the biodegradable plastic sheet was comparatively higher than non-woven cloth and high temperature induces male flowers.

The days to first female flower exhibited a range of 54 to 62 days. Treatment T7 took minimum days to first female flower (54 days) followed by T6, while maximum was recorded in T1 (62 days). Days to first harvest ranged from 83 (T5) to 91 (T1) days. The crop raised under tunnel (T2) attained the harvestable maturity on 19th March in comparison to 10th May under open filed sowing (T7) which

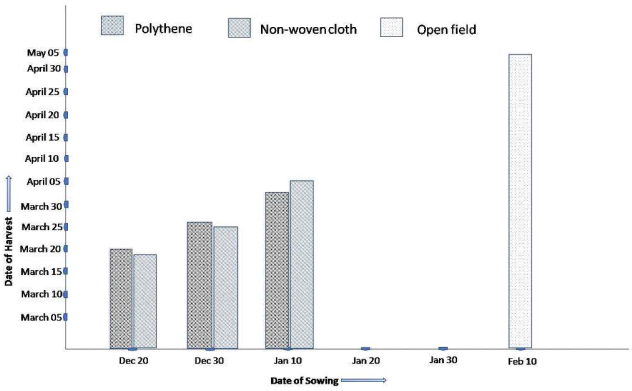

Fig. 3. Effect of sowing time on crop advancement of water melon under low tunnel and open field

was 52 days later than the low tunnel (Fig. 3). Thus, tunnel facilitates the early harvest of crop which can earn higher market price in off-season than the normal season. The importance of early harvest in watermelon for grabbing an early market opportunity has also been mentioned by Anumala et al (2020). Low tunnel creates favourable microclimate condition by increasing the temperature at that time for the crop which induces early flowering, fruiting and harvesting. Modification in climatic conditions, promoting earlier flowering and harvesting by low tunnels has also been reported by earlier researchers (Ogden and Iersel 2009). Ibarra et al (2001) also found that muskmelon crop raised under plastic cover reached flowering 24 days earlier than uncovered plants. Similarly, an advancement of 40-50 days was achieved with the use of low tunnel in long melon crop as compared to crop raised under open field condition (Verma et al 2019). The mean number of days taken to last harvest ranged from 101 (T1) to 109 (T5) days.

Yield attributing parameters: The fruits per plant, fruit diameter, fruit weight and fruit yield were significantly influenced by the sowing date and covering material. The fruits were harvested at marketable stage when fruits were ripened. Total number of fruits per plant ranged from 2.64 (T7) to 3.78 (T5). The treatment T6 recorded maximum fruit diameter (18.3 cm) followed by T5, T4 and T3 which were statistically at par with each other, while minimum fruit diameter was in T7 (15.4 cm). The treatment T6 recorded maximum fruit weight (2.85 kg) followed by T5, T4 and T3 and the minimum weight of fruit was recorded in T7 (2.28 kg). The fruit yield per hectare ranged from 156.78 to 256.32 q. The T5 recorded the maximum fruit yield per hectare (256.32 q) followed by T6, T3 and T4 and the minimum were recorded in T7 (156.78 q). The higher yield under tunnel might be due to better growth and development of all yield attributing traits than open condition which increases the net photosynthesis and availability of assimilates for individual plants to grow and produce high yield. Higher yield under tunnel than open field condition was also supported by fruiting duration as the treatment having the highest yield had 26 days of fruiting duration in comparison to open field condition which had 16 days of fruiting duration only. Low tunnels benefit vegetable production by extending the growing season, increasing yields, and increasing quality. With the use of tunnels, it is possible to harvest watermelon crop up to 50 days earlier in the spring and extend the growing season. Due to this low tunnel made the difference in comparison to open field because the produce harvested during second week of March from low tunnel was sold at Rs. 15-30 per kg against Rs. 5-10 per kg from the produce harvested during first week of May from open field. Yield and quality are increased under tunnels due to a longer production season and the exclusion of rain, wind, and severe weather events. Ibarra et al (2001) achieved early harvests and higher yields with the use of row covers and plastic mulch compared to plants grown without cover. Zhao et al (2014) also reported higher yield of tomato and brinjal under high tunnel. Maragal et al (2018) also found better plant growth, yield and quality of bitter gourd var. Pusa Rasdar under the insect-proof net house. Similarly, Verma et al (2019) also found that better yield and quality produce can be obtained by sowing the long melon crop during winter with the use of low tunnel as compared to open field crop cultivation. The lowest yield in T7 (sowing on 10th February) might be due to coincidence of flowering, fruit set and development with extremes of temperature which acts as

Table 2. Effect of sowing date and covering material under low tunnels on flowering and yield attributes of watermelon

Treatments	Days to first male flower (DAS)	Days to first female flower (DAS)	Days to first harvest (DAS)	Days to last harvest (DAS)	Fruiting duration (Days)	No. of marketable fruits/ plant	Fruit diameter (cm)	Fruit weight (kg)	Marketable fruit yield per ha (q)
T1 (20th December with polythene sheet)	56	62	91	107	16	3.08	16.9	2.53	214.85
T2 (20th December with non-woven cloth)	57	61	89	105	16	2.96	16.7	2.45	209.67
T3 (30th December with polythene sheet)	55	58	87	105	18	3.42	17.3	2.65	221.72
T4 (30th December with non-woven cloth)	54	59	86	102	16	3.35	17.8	2.71	217.25
T5 (10th January with polythene sheet)	51	57	83	109	26	3.78	18.1	2.82	256.32
T6 (10th January with non-woven cloth)	49	56	85	108	23	3.56	18.3	2.85	232.64
T7 (10th February under open condition)	51	54	84	101	16	2.64	15.4	2.28	156.78
CD (p=0.05)	0.41	3.38	3.69	4.03	3.17	0.49	1.75	0.34	22.53

Crop raised under tunnel in fruiting stage

Crop raised under open field in flowering stage

Fruits from open field

Fruits from low tunnel

Fig. 4. Effect of micro-climate modulation on fruit cracking of watermelon

stress to plants which limit the growth and developments of fruits and also under temperature stress, plants failed to produce male flower leads to reduced pollination and fruit set of cucurbits resulting in smaller fruit size and lower yield (Wehner and Guner 2004).

Quality parameters: The crop raised under tunnel produced better quality produce than the crop raised under open field condition. Fruit cracking is a major problem in watermelon under open field condition of hot arid environment. There was significant difference for fruit cracking incidence between the fruits harvested from low tunnel and the fruits harvested from open field condition. Fruit cracking incidence ranged from 35.1-40.5 % under open field harvest as compared to 5.6-10.2 % under low tunnel harvest. The crop grown under tunnel had vigorous growth and attained fruit harvesting during third week of March with less fruit cracking which altogether contributed for better quality produce as compared to open field crop (Fig. 4).

Economics: Net income and cost benefit ratio was significantly influenced by date of sowing and growing conditions. Net income and cost benefit ratio of sowing under low tunnel was significantly higher than the sowing under open field condition and the highest economics (B:C ratio of 2.00) was achieved by sowing the crop on 10th January under tunnel with non woven cloth followed by polythene sheet. Though, the cost of cultivation under tunnel was higher than the open field condition, the higher market price of off-season produce from low tunnel resulted in higher economic returns than open field cultivation .

CONCLUSION

The low tunnel technology can be successfully used to harvest early and off season produce of watermelon with better quality which fetches higher price in the market than normal season. The sowing on 10th January with polythene sheet was the best in terms of yield and fruiting duration followed by the sowing on same date with non-woven cloth covering. Thus, with the adoption of low tunnel technology, the crop of watermelon can be advanced by 40-50 days as compared to normal season (open field) cultivation thereby ensuring maximum benefit to the farmer against per unit of area and cost invested.

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Nursery Performance of different Pear Cultivars on Quince Rootstocks under Sub-temperate Zone of India

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***Abstract*:** Intact stature of plant is basic requirement for any high-density plantation system which can effectively be induced by the use of dwarfing rootstock. In pear, quince rootstocks impart dwarfness; however, it may also result in graft failure due to graft incompatibility. Therefore, morphological and physiological evaluation of pear cultivars including Carmen, Concorde, Red Bartlett and Packham's Triumph on three quince rootstocks (Quince A, BA 29, Quince C) and Kainth was carried out in the northwestern Himalayan region of India. All stionic combinations exhibited successful graft union formation after one year with substantial variations in morphological parameters. Graft success ranged from 61.14 to 90.00% with the highest registered by Carmen grafted on Kainth and Quince A combinations. Plants grafted on Quince A attained maximum mean height while minimum height was acquired by plants on Quince C rootstock. Further, the maximum plant height (95.15 cm), shoot length (74.96 cm), rootstock diameter (10.34 mm), bark thickness (2.02 mm) and wood thickness (7.27 mm) was recorded in plants of Carmen/Quince A stionic combination. Most dwarf and compact plants were obtained in stionic combination of Red Bartlett over Quince C which suggests the suitability of this combination in high density planting system. Graft success was correlated positively with plant height and negatively with graft union diameter. However, further studies are required to validate the long-term efficiency of this rootstock on tree growth, fruit yield and quality characteristics.

***Keywords*:** Quince, Scion-stock, Grafting, Dwarf rootstock, Graft take success

Pear is gaining acceptability and importance worldwide owing to its delicious taste and high nutritional value. Pear cultivation represents a significant market potential for producers. In India, pear cultivars like Bartlett, Conference and Patharnakh are mainly cultivated in hilly sub-temperate to temperate regions. Consumer preference is, however, increasing towards coloured varieties such as Red Bartlett and Carmen; and other European cultivars including Concorde and Packham's Triumph. Carmen (Guyot×Bella di Giugno) is an early bearing pear cultivar with a high yielding capacity and attractive red peel on maturity. The fruits ripen two weeks earlier and have better shelf-life than the Bartlett pears (Ingels 2016), while cultivar Concorde (Conference×Doyenne du Comice) and Packham's Triumph (Uvedale's St. Germain×Williams's) are late-season cultivars having green coloured fruits with the yellow and creamy coloured pulp, respectively (Quinet and Wesel et al 2019). These cultivars were introduced in India in the recent past and the demand for their planting material is escalating as a consequence of better shelf life, attractive shape and fruit colour leading to the high market price. The selection of quality planting material is the foremost requirement of any orchard enterprise.

In India, old plantations of pear are under a conventional low-density planting system which is responsible for its lower productivity in spite of favorable meteorological conditions and the hardy nature of this crop. In the last decades, there has been a tremendous increase towards using grafted/budded plants for orchards. Traditionally, pear plants were raised on Kainth (*Pyrus pashia*) rootstock; however, now-a-days high density orcharding is possible due to availability of different size controlling clonal rootstocks including Quince, 'Old Home' 'Farmingdale' (OHF), Fox and Pyrodwarf (Abdollahi and Hassani 2021). Dwarf plants are easy to maintain and harvest and these plants harness maximum sunlight and produce fruits of superior quality. Rootstocks influence tree morphological parameters like tree growth and vigour, precocity, productivity, and nutrient absorption (Khadivi-Khub and Anjam 2016) and scion also exerts a reciprocal effect on rootstock.

Quince has been proven to induce precocity, improve the productivity and quality of some European pears (Stern et al 2013, Donadio et al 2019), however; prior studies have shown that it exhibits incompatibility with some pear cultivars (Santos-Pereira et al 2021). Incompatibility is the abnormal development of the graft that usually occurs while grafting rootstock and scion from different genera or species. The suitability of rootstocks may vary from region to region due to

prevailing varied climatic conditions. Hence, the selection of rootstock should be made based on the conditions of the region where the orchard is to be established and the cultural practices to be followed (Machado et al 2018). Limited information is available on the impact of Quince rootstocks on newly introduced pear cultivars in the northwestern Himalayan region. Therefore, the study was carried out to check the suitability and determine the effect of the growth and development characteristics of nursery plants of Quince rootstocks on cultivars Carmen, Concorde, Packham's Triumph and Red Bartlett in nursery.

MATERIAL AND METHODS

The study was conducted at Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP, India (30° 51'N; 77° 88'E; 1300 m amsl) during the year 2018. The climate of this region is sub-temperate with moderate summers and distinct winters. Soil pH and electrical conductivity of the experimental location were 6.8 and 0.32 dSm^{-1}, respectively. Raised nursery beds (3×1 m) were prepared after leveling the surface and one-year-old rootstocks including Quince A, BA 29, Quince C and Kainth were planted with a spacing of 25×20 cm during the last week of December 2018. Bed planting was done in three rows and every row contained ten plants. After proper establishment, these rootstocks were grafted with one year old scion of different cultivars *viz*., 'Carmen', 'Concorde', 'Packham's Triumph' and 'Red Bartlett' at the height of about 15 cm above ground level by using tongue grafting method during the first week of February 2019. The plants were subjected to uniform cultural practices such as mulching, irrigation, de-shooting, weeding and spraying of insecticides and fungicides, which were carried out as per standard practices. The experiment was a randomized complete block with three replications and ten plants per replication. Observations related to morphological parameters such as graft take success, plant height, shoot length, diameter of rootstock, scion and graft union, leaf area, number of stomata, size of stomata, dry weight of root and shoot, root length, wood and bark thickness were recorded at the end of growing season. In order to judge the incompatibility symptoms, overgrowth above and below was observed visually. Data was processed using SAS package (9.3 SAS Institute, Inc, USA). Analysis of variance was carried out with Tukey's HSD for statistical analyses.

RESULTS AND DISCUSSION

Graft take success, plant height and shoot length: Different rootstocks had a significant effect on the graft take success, with maximum value in plants grafted on Kainth rootstock (95.67%), followed by Quince A (91.67%) rootstock. Minimum graft take success to the tune of 81.67% was recorded on Quince C rootstock (Fig. 1). The impact of different cultivars on graft take success was also statistically significant. Cultivar Carmen recorded graft take success of 95.83%, which was significantly higher than all the other cultivars tested, while cv. Red Bartlett had the minimum success (85.83%). The interactions between the rootstocks and scion cultivars were also significant. Cultivar Carmen grafted on Kainth and Quince A rootstocks were superior over all the stionic combinations and recorded the highest graft take success (100%), which was followed by Red Bartlett grafted on Kainth (96.67%). Maximum dwarfing effect was induced by Quince C which suppressed the plant height and shoot length by 22.19% and 29.15%, respectively, in comparison to Quince A. However, with respect to Kainth the reduction in plant height and shoot length on Quince C rootstock was 14.94 and 26.73%, respectively. Considering the cultivars, Carmen registered the maximum plant height and shoot length, followed by Packham's Triumph. Minimum growth was in Red Bartlett showing a reduction of 24.56% plant height and 45.32% shoot length in comparison to Carmen. Among various stionic combinations, the maximum plant height (95.15 cm) and shoot length (74.96 cm) was in plants of Carmen grafted on Quince A rootstock, followed by plants of cultivar Packham's Triumph grafted on Quince A rootstock. However, the lowest plant height (49.34 cm) and shoot length (29.38 cm) were in the plants of cultivar Red Bartlett grafted on Quince C rootstock. Plant height of stionic combination Red Bartlett on Quince C was statistically at par with Red Bartlett on Quince A, while shoot length was found at par with Red Bartlett grafted on BA 29 and Quince A rootstock (Table 1). Higher plant height and shoot growth of Carmen on Quince A and Kainth rootstock might be attributed to high vigour potential of these rootstocks and scions. Differences in plant height could be due to the effect of different levels and proportions of auxin and cytokinin found in the apical meristem of pear varieties (Rahman et al 2017).

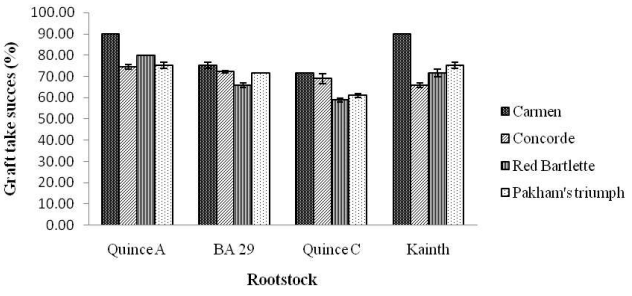

Fig. 1. Influence of different rootstocks and scion combinations on graft take success (%)

Scion, stock and graft union diameter: Growth variations at scion, stock and graft union were reported in all the stionic combinations, with a maximum diameter at the point of graft union followed by rootstock which was measured 5 cm below the graft union and lowest on the scion portion of the plant. Evaluating the rootstocks, plants on Quince A had 20.93 and 11.87% higher rootstock diameter and scion diameter, respectively, than plants on Quince C. However, the graft union diameter was reported maximum in Quince C and BA 29; and was approximately 25.92 and 6.46% greater in comparison to Kainth and Quince A rootstocks, respectively. Considerable effects of scion cultivar on rootstock diameter, scion and graft union diameter were also detected. Scion cultivars brought about smaller changes in rootstock diameter with maximum variation of ~6.40%, whereas the scion diameter was 33.22% higher for Carmen in comparison to Concorde. Cultivar Red Bartlett attained maximum graft union diameter (13.31 mm), which was 13.60% more than Packham's Triumph. In different stionic combinations, the rootstock diameter ranges from 7.18 mm (Concorde on Quince C) to 10.34 mm (Carmen on Quince A), while the scion diameter varied from 5.18 mm (Concorde on BA 29) to 9.95 mm (Carmen on Quince A) and the graft union diameter fluctuated from 9.61 mm (Concorde on Kainth) to 14.72 mm (Red Bartlett on Quince C) (Table 1). The vigorous growth of Carmen on Quince A rootstock might have accounted for higher scion and rootstock diameter. Bartlett has been reported as incompatible with Quince C rootstock (Habibi et al 2022), the higher graft union diameter of Bartlett on Quince C in the present study may be due to poor graft union formation. Machado et al (2015) associated greater vigour with the compatibility in the grafting region, which is due to continuous flow between the conducting vessels of the rootstock and graft. Accumulation of metabolites, presumably phenols and carbohydrates, as a result of partial cambium continuity at the union could be attributed to increased stem diameter at the union (Mng'omba et al 2007). High levels of callus forming into the undifferentiated parenchymatous cells could also cause the union to swell. If the graft partners are of equal size, the scion tends to produce more callus tissue possibly due to increased basipetal transport of photosynthates (Adams 2016).

Leaf area, stomata density and size of stomata: Plants grafted on Quince A rootstock had significantly higher leaf area (16.99 cm^2) while the minimum leaf area was for Quince C rootstock which was 11.83% lower than on the Quince A

Table 1. Effect of different stionic combinations on plant height, shoot length, diameters of root, scion and on graft union

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Plant height (cm)	Quince A	95.15a	69.51cd	52.81ef	89.53a
	BA 29	75.52bc	65.03d	69.15cd	77.58b
	Quince C	68.41d	56.03e	49.34f	65.11d
	Kainth	76.82b	65.93d	67.02	71.05bcd
Shoot length (cm)	Quince A	74.96a	49.68ef	32.76gh	69.41b
	BA 29	56.13cd	46.19f	30.63h	58.05c
	Quince C	47.81ef	37.75g	29.38h	45.76f
	Kainth	57.08c	46.63ef	48.26ef	51.68de
Stock diameter (cm)	Quince A	10.34a	10.16ab	10.12ab	10.25ab
	BA 29	10.13ab	10.06ab	9.86ab	8.28cd
	Quince C	9.16bc	7.18d	8.23cd	7.79d
	Kainth	9.15bc	9.79ab	10.14ab	9.99ab
Scion diameter (cm)	Quince A	9.95a	5.52gh	7.97bcde	8.94ab
	BA 29	8.27bcd	5.177h	7.50cde	7.59cde
	Quince C	8.93ab	5.95gh	6.37fg	7.26def
	Kainth	8.49bc	7.17ef	7.90bcde	8.47bc
Graft union diameter (cm)	Quince A	12.80bc	12.54c	14.35ab	10.68d
	BA 29	13.54abc	13.49abc	14.07abc	12.70bc
	Quince C	13.49abc	12.59c	14.72a	13.03abc
	Kainth	10.60d	9.61d	10.09d	9.60d

Values in same column with different letters indicate statistically significant differences at $p \leq 0.05$

grafted plant. Among cultivars, Carmen had comparatively larger leaves and accounted 29.80% greater leaf area was observed in comparison to the Concorde cultivar having the lowest leaf area. The interactions between rootstock and scion have no significant effect on leaf area (Table 2). Ozturk and Ozturk (2014) reported that leaf area is directly proportional to the vigour of the rootstock and the leaf area ultimately influences the overall growth of the plant. It was observed that only cultivars exhibited a significant influence on stomata density as these are genetically governed characteristics of a species. Statistically higher numbers of stomata (253.44 per mm^2) were in plants of cultivar Carmen, while the other three cultivars including Red Bartlett, Concorde, and Packham's Triumph did not show much variation among each other. Likewise, the size of stomata was maximum in cultivar Carmen (496.67 μ^2) and the minimum size of stomata was observed in cultivar Concorde (376.03 μ^2) (Table 2). These results are in contrast with the findings of Dhillon et al (2008), Serra et al (2014) and Zhou et al (2020) where plants grafted on dwarf rootstocks have lower stomata density and size in comparison to vigorous ones.

Root length and dry weight percentage of roots and shoots Root length was precisely influenced by both scion, rootstock. However, interaction did not have a significant effect on root length (Table 2). Longest roots were depicted on the Quince A rootstock to the tune of 0.93 m, which was statistically at par with the Kainth rootstock (0.91 m), while the Quince C rootstock registered the minimum root length (0.76 m). Among cultivars, Carmen had the maximum root length of 0.93 m, which was approximately 15% higher than Red Bartlett. These results are in consonance with the findings of Harrison et al (2014). The dry weight of shoots was affected by the rootstock and the interaction between rootstock and scion (Table 3). Scion alone didn't contribute to dry matter accumulation in grafted pear plants. The dry matter content of shoots ranged from 48.88 to 63.45% in Red Bartlett on BA 29 and Carmen on Quince A, respectively. Among rootstocks, plants on Quince A had maximum dry matter (59.86%) followed by Kainth (56.06 %). However, dry matter accumulation in roots was affected by rootstock only with the maximum average percentage reported in Quince A (67.91%) and minimum in Quince C (64.82%). The impact of scion on root growth might be due to the hormonal make-up of a plant, which is governed by the scion cultivar. Significant variation in the ability of rootstocks for overall nutrient uptake and their partitioning causes a difference in dry matter accumulation in scion (Valvelri and Kalcsits 2021). The vigorous scion supplies more carbohydrates to the root system, hence positively influencing the root biomass and vice-versa (Valvelri et al 2019).

Bark and wood thickness: The influence of rootstocks on bark thickness was non-significant, but it had a substantial effect on wood thickness (Table 3). The maximum bark (1.79

Table 2. Influence of different stionic combinations on plant leaf area, number of stomata, size of stomata and root length

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Leaf area (cm^2)	Quince A	21.78a	15.28cdef	18.62abc	12.29fghi
	BA 29	20.59ab	14.53efg	17.97bcd	10.78hi
	Quince C	21.69a	14.72defg	17.68bcde	9.80i
	Kainth	18.23bc	13.22fgh	16.96cde	11.52ghi
Number of stomata (Per nm^2)	Quince A	252.50ab	207.30abc	217.71abc	230.84abc
	BA 29	250.42ab	208.34abc	200.42bc	215.00abc
	Quince C	264.59a	200.96bc	212.29abc	226.67abc
	Kainth	246.25abc	209.67abc	189.17c	218.75abc
Size of stomata (μ^2)	Quince A	582.13a	493.72a	331.48a	363.63a
	BA 29	532.60a	563.11a	408.65a	305.78a
	Quince C	444.96a	352.84a	400.65a	386.78a
	Kainth	427.00a	381.71a	537.24a	447.94a
Root length (m)	Quince A	1.00a	0.89cde	0.86def	0.95abc
	BA 29	0.89cde	0.77ghi	0.75hi	0.83defg
	Quince C	0.82efgh	0.74hi	0.70i	0.79fgh
	Kainth	0.99ab	0.88cde	0.85defg	0.92bcd

Values in same column with different letters indicate statistically significant differences at $p \leq 0.05$

mm) and wood thickness (6.04 mm) were in the plants grafted on Quince A rootstock and Kainth, respectively. However, minimum bark thickness (1.67 mm) and wood thickness (5.00 mm) was observed in plants grafted on Quince C rootstock. The effect of scion on bark and wood thickness was significant. Cultivar Carmen attained maximum bark thickness (2.00 mm) and wood thickness (6.34 mm). The second highest value for bark thickness was obtained in the plants of cultivar Packham's Triumph, which was statistically at par with cultivar Concorde. Minimum bark thickness of 1.47 mm and wood thickness of 4.14 mm were recorded in the plants of cultivar Red Bartlett and Concorde, respectively. The maximum value for bark thickness of 2.02 mm and wood thickness of 7.27 mm was recorded in cultivar

Table 3. Influence of different stionic combinations on dry weight of shoots, dry weight of roots, wood thickness and bark thickness

Parameter	Rootstock	Scion			
		Carmen	Concorde	Red Bartlett	Packham's Triumph
Dry weight of shoots (%)	Quince A	63.45a	62.47ab	61.76ab	51.56abc
	BA 29	55.73abc	50.82bc	48.88c	56.91abc
	Quince C	52.79abc	50.96bc	55.06abc	51.75abc
	Kainth	56.78abc	56.36abc	53.79abc	57.29abc
Dry weight of roots (%)	Quince A	68.00ab	68.91a	67.48ab	67.24ab
	BA 29	63.79ab	65.78ab	66.43ab	63.99ab
	Quince C	61.72b	64.93ab	66.81ab	65.84ab
	Kainth	66.69ab	64.89ab	66.05ab	66.56ab
Wood thickness (mm)	Quince A	7.27a	3.38f	5.82abc	6.50ab
	BA 29	6.00abc	4.17def	5.56bcd	5.43bcd
	Quince C	6.24ab	3.69ef	4.58cdef	5.49bcd
	Kainth	5.92abc	5.32bcde	6.61ab	6.32ab
Bark thickness (mm)	Quince A	2.02a	1.79abc	1.51bcd	1.85ab
	BA 29	1.99a	1.69abcd	1.47cd	1.78abcd
	Quince C	1.96a	1.66abcd	1.41d	1.67abcd
	Kainth	2.01a	1.79abc	1.49bcd	1.82abc

Values in same column with different letters indicate statistically significant differences at p≤0.05

Table 4. Correlation among different morphological parameters of different stionic combinations

Parameters	Plant height	Rootstock diameter	Scion diameter	Graft union diameter	Number of stomata	Size of stomata	Dry weight of shoot	Dry weight of root	Bark thickness	Wood thickness	Graft take success
Plant height	1										
Rootstock diameter	.400**	1									
Scion diameter	.620**	.311*	1								
Graft union diameter	-.057	.015	-.092	1							
Number of stomata	-.293*	-.112	-.455**	.087	1						
Size of stomata	.247	.459**	.041	-.058	.091	1					
Dry weight of shoot	.903**	.260	.620**	-.080	-.258	.201	1				
Dry weight of root	.875**	.353*	.587**	-.175	-.333*	.242	.941**	1			
Bark thickness	.628**	.187	.470**	-.186	-.074	.212	.675**	.687**	1		
Wood thickness	.537**	.364*	.843**	-.151	-.572**	.063	.508**	.509**	.213	1	
Graft take success	.638**	.437**	.579**	-.319*	-.090	.353*	.697**	.683**	.553**	.527**	1
Leaf sugar	-.177	-.576	-.118	-.246	-.073	-.177	-.194	-.289	-.069	-.197	-.318
Leaf starch	-.775	-.484	-.469	.278	.227	-.183	-.742	-.777	-.531	-.443	-.693

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

Carmen grafted on Quince A rootstock, whereas the minimum bark thickness (1.41 mm) and wood thickness (3.38 mm) was in cultivar Red Bartlett grafted on Quince C rootstock and Concorde grafted on BA 29 rootstock, respectively. Maximum wood thickness in Carmen on Quince A might be due to strong compatibility, which causes better growth, more leaf area and assimilation of more photosynthates within the plant. A smaller wood/ bark ratio has been reported in standard-type pears in comparison to dwarf types (Chen et al 2015).

Correlation analysis revealed a positive correlation between plant height and diameters above and below the graft union (scion and stock diameters, respectively), for all the stionic combinations, while a significant negative correlation between the plant height and diameter at the graft union was reported. Higher swelling at the graft union on dwarf plants might be attributed to vascular discontinuity due to phloem degeneration and discontinuity of the xylem vessels in the graft union region. This causes obstruction in the ascending sap flow through the xylem and the descent of photo assimilates through the phloem (Ciobotari et al 2010, Machado et al 2017), which results in poor graft take success and graft incompatibility. The graft take success and graft union diameter were negatively correlated. Certainly, the plant height was positively correlated with the dry weight of shoot and root and graft take success (Bark thickness, wood thickness and plant height were also correlated, although the correlation between bark and wood thickness was weak. The non-significant correlation was registered for the number and size of stomata). Individually, the number of stomata was negatively correlated with plant height, whereas the size of stomata was positively correlated with plant height (Table 4).

CONCLUSION

Overall growth of the plant was affected by use of different rootstocks and scions. The plants grafted on Quince C rootstock and resulted in compact architecture. Quince A was vigorous in comparison to seedling rootstock Kainth. However, the combination of Red Bartlett on Quince C was found to be most dwarfing, which suggests its suitability for high density orcharding. However, in this study the confounding effects of management practices were not considered. Therefore, further studies are required to evaluate the effect of various orchard management practices.

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Influence of Environmental Factors, Growing Conditions and Seasonal Variations on Vegetative, Yield and Quality Characters of Cucumber (*Cucumis sativus* L.) Varieties

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***Abstract*:** The cultivation of cucumber is a major problem under open environmental conditions because it is highly susceptible to biotic and abiotic conditions. The present study involves the cultivation of two monoecious cucumber varieties Swarna Sheetal and Solan Srijan under open and protected conditions in two seasons for vegetative, yield and quality. The maximum vegetative growth attributes such as vine length at 30, 45, 60, final harvest stage and maximum leaves and branches were in the summer season crop of the Solan Srijan variety. Economic yield maximum in the summer crop of Solan Srijan variety compared to the Swarna Sheetal . Solan Srijan variety given the maximum amount of ascorbic acid in winter season under protected conditions and a lesser amount of acidity was in the Swarna Sheetal in the winter season under open environmental conditions. The summer season has recorded maximum temperature influences the vegetative growth as well as yield under protected conditions. Thus, growing environmental conditions and seasonal variations are important factors that could be effective on the vegetative, yield and quality characters of cucumber varieties.

***Keywords*:** Monoecious, Protected condition, Solan Srijan, Swarna Sheetal

Cucumber (*Cucumis sativus* L.) is a prominent vegetable crop distributed across the world (Soleimani et al 2009) and is indigenous to South Asia, specifically the warm and humid environment of the Himalayas in Northwest India and Northern Africa. Cucumber responds best in conditions of high temperature, humidity and light intensity with an adequate supply of water and nutrients. Open field grown vegetables are susceptible to abiotic and biotic stress, which reduces the quality and productivity of cucumbers. Protected farming can minimize both biotic and abiotic stresses. The dry season in southern India lasts from April to June, while the rainy season lasts from June to October. In northern India lasts from April to July, while the rainy season lasts from July to October (Ramesh and Arumugam 2010). Temperature, relative humidity and rainfall are the primary climatic elements that influence cucumber development with a significant extent of yield. A greenhouse microclimate is the combination of climatological elements that form around a live plant. It is essential to monitor and maintain these factors at their optimal levels for improved crop growth and yields. The heating system, ventilation and fogging system, lighting and shading system, fertigation system and may all be used to regulate the greenhouse environment. Thus, the investigation aimed to determine the influence of climatic factors and seasonal variability in the cultivation of cucumber in the naturally ventilated poly house compared to an open field on the growth, yield and quality of cucumber fruit.

MATERIAL AND METHODS

Experimental details: The study was conducted at field conditions of Horticultural College and Research Institute, Periyakulam, TNAU, Tamil Nadu, located at a longitude of 10^0 13' North and 77^0 59' East. It is located at an altitude of 289 m above mean sea level (MSL). The crop was raised in two seasons *i.e*., the summer and winter seasons of 2022 under open fields and protected conditions. Two monoecious cucumber varieties *i.e*., Swarna Sheetal and Solan Srijan seeds are collected from Indian Council Agricultural Research (ICAR) Institutes and these seeds were used as planting material for this study. The standard cultivation practices were followed.

Meteorological observations in protected and open field conditions: Weather data were recorded at weekly intervals during the summer and winter months of the cropping period. Weekly means of data on temperature (°C), and relative humidity (%) were obtained from the nearby Agrometeorological Observatory, Horticultural College and Research Institute, Periyakulam for the period of study. In

protected conditions, the temperature was regulated through the timely opening and closing of the top shade net, fan and pad system and fogging for improved plant growth, because the temperature is a primary regulator of development processes. During the growing season, relative humidity was moderate and it was regulated chiefly by foggers, cooling fan pad system and shade net.

Estimation of total soluble solids (°Brix): Macerated juice from mature cucumber was placed over the prism of a Digital Pocket Refractometer Pal-1, Atago (range 0 to 32) and the brix value was recorded the process was repeated three times for each sample and the mean value was calculated.

Estimation of ascorbic acid (mg/100 g): The dye solution was prepared by mixing 50 mg dye with 42 mg sodium hydrogen carbonate in 150 ml of hot distilled water. 20 g oxalic acid was added to 500 ml distilled water (A) and thoroughly mixed. After that, added 100 mg of ascorbic acid to 100 ml of solution A (B) and mixed well. After that, 90 ml of oxalic acid was added to 10 ml of solution B. Titrated with dye solution until light pink colour appeared after removing 5 ml and adding 10 ml oxalic acid (4 per cent). Crushed the fruit and extracted a clear 15 ml juice, then 100 ml oxalic acid (4 per cent) was added to each and mixed thoroughly. Then, take 5 ml and add 10 ml oxalic acid (4 %) was added to it. Then titrate with dye solution until a bright pink colour appeared.

$$\text{Ascorbic acid} = \frac{0.5\text{ mg}}{V_1} \times \frac{V_2\text{ (ml)}}{5\text{ ml}} \times \frac{100}{\text{weight of the sample}} \times 100$$

Determination of acidity (%): Acidity was calculated by titrating the cucumber juice with 0.1 N Sodium hydroxide (NaOH) using Phenolphthalein as an indicator and expressed as per cent acidity.

$$\text{Acidity (\%)} = \frac{\text{Equivalent weight of acid} \times \text{Normality of NaoH} \times \text{Titre value}}{\text{Weight of sample}} \times 100$$

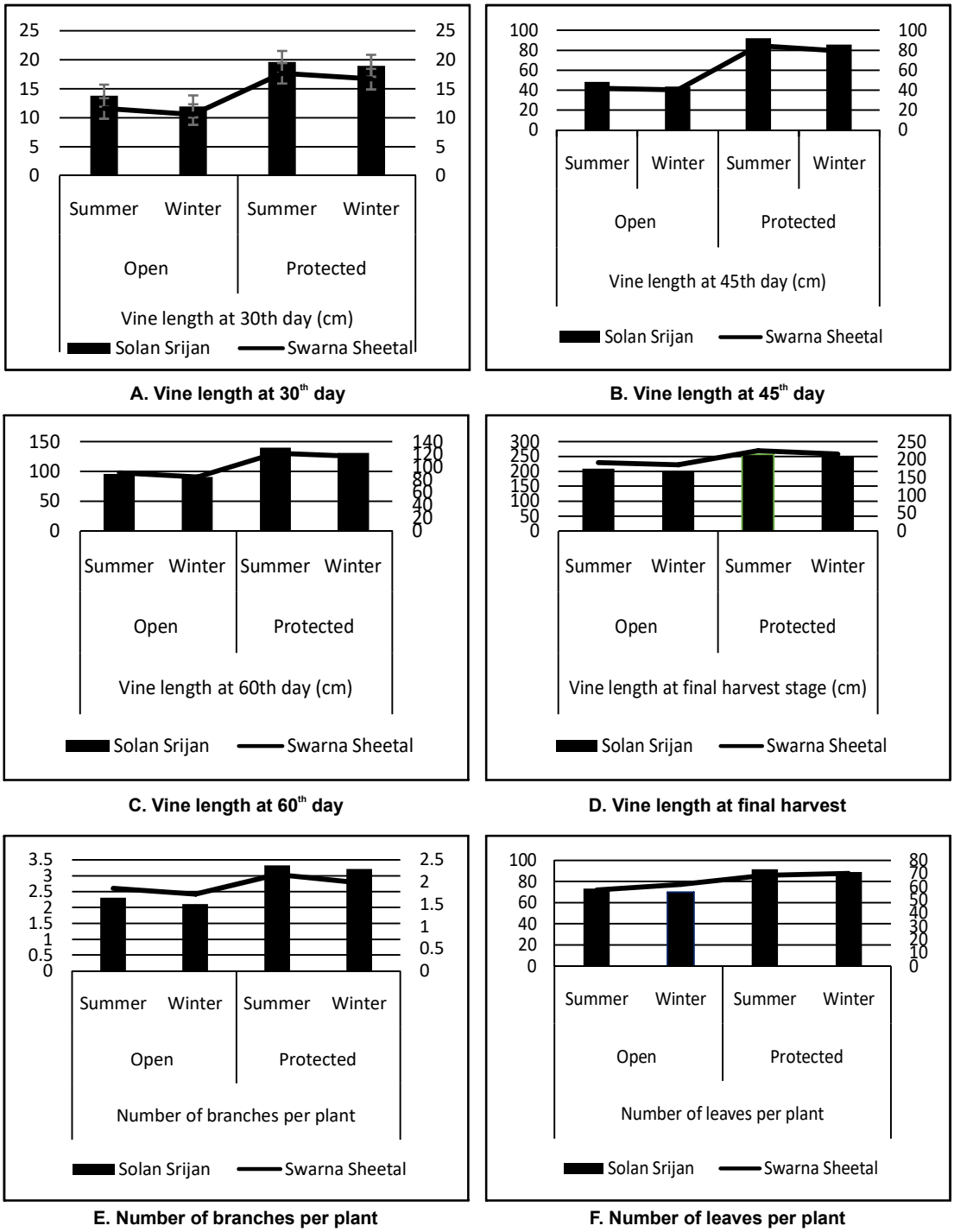
RESULTS AND DISCUSSION

Vegetative growth parameters: Plant growth attributes of two cucumber varieties *i.e.*, Swarna Sheetal and Solan Srijan showed significant differences in two seasons (summer and winter) under two growing conditions *i.e.,* open and protected conditions. Under the open environmental conditions, Solan Srijan variety had the maximum vine length at 30th, 45th, 60th day and at the final harvest stage (209.6 cm) during the summer season crop. In protected conditions, Solan Srijan variety were recorded maximum vine length at the 30th day, 45th day, 60th day and at final harvest stage (256.51 cm) in summer season crop. The maximum vegetative growth was obtained under protected condition compared to open environmental condition while summer season crop gave maximum vegetative growth compared to open environmental condition. When compared to open condition, in protected condition, there was significant difference in sunlight received and radiated out which enhanced the internal temperature and also better and increased photosynthesis resulting in greater vegetative growth and maximum temperature recorded in summer season of protected condition. Solan Srijan variety had the maximum number of branches per plant (2.31) under open field environmental conditions in the summer season crop and lower number of branches per plant (1.73) was in Swarna Sheetal variety in winter season crop. Under controlled atmosphere condition, Solan Srijan variety had the maximum number of branches per plant under summer season crop and lower number of branches (1.98) was in Swarna Sheetal variety in winter season crop (Fig. 1). In general, plants tend to reduce surface area to minimize evapotranspiration. But in protected condition such situation may not arise. Hence, the plants vigorously grew by way of putting forth a higher number of branches and leaves. This might be the reason for having higher number of branches under protected conditions.

Flowering parameters: Solan Srijan variety recorded maximum number of leaves per plant (73.2) in the summer season crop and Swarna Sheetal variety had lower number of leaves (57.5) in the summer season crop. Under controlled atmosphere conditions, Solan Srijan variety recorded greater number of leaves (91.66) in summer season crop compared to the winter season crop (89.11) and lower number of leaves (68.48) was in summer season crop of Swarna Sheetal variety compared to winter season crop (69.91) (Fig. 1). The variation in the number of leaves among ten varieties at different stages of growth might be owing to the distinct varietal inherent genetic makeup of a specific variety, resulting in variations in phenotypic expression. Protected condition supported the growth of the variety by altering the natural habitat and microclimatic conditions around the plants. The number of leaves varied greatly. Similar trends in the total number of leaves were observed by Ahmed et al (2004) in cucumber and Olaniyi et al (2010) in tomato.

Yield parameters: The open environmental condition Solan Srijan variety had the maximum fruit length (19.56 cm) in the summer season crop and Swarna Sheetal variety recorded lowest fruit length (15.43 cm) in winter season crop compared to the summer season crop (16.66 cm). Under the protected environmental condition, Solan Srijan variety grown crop recorded maximum fruit length (20.06 cm) compared to Swarna Sheetal variety in summer season crop (17.83 cm). The variation in fruit length might be caused by genetics, environmental factors or crop vigour. The results agreed with the findings of earlier workers in cucumber crop

(Yadav et al 2012, Ullah et al 2012, Kumar et al 2013, Patel et al 2013). The highest fruit diameter (4.43) and fruit volume (176.33) was in Swarna Sheetal variety grown in summer season crop compared to winter season crop (4.21, 174.54 cm^3, respectively). Under protected environmental condition, the maximum fruit diameter (4.53 cm) was in Swarna Sheetal variety grown in summer season crop and higher fruit volume (184.87) was in Solan Srijan variety grown in summer season crop. Varietal differences and growing conditions were the reasons for the variation observed. Similar trend was observed by earlier workers in cucumber (Ullah et al 2012, Kumar et al 2013, Patel et al 2013, Rawat et al 2014).



A. Vine length at 30th day **B. Vine length at 45th day**

C. Vine length at 60th day **D. Vine length at final harvest**

E. Number of branches per plant **F. Number of leaves per plant**

Fig. 1. Effect of growing conditions and seasonal variations on vegetative parameters of cucumber varieties

Fruit weight attribute showed a significance difference among the growing conditions and growing seasons. Under open grown condition, the maximum fruit weight (241.03 g) was in Solan Srijan variety of summer season crop and lowest fruit weight (174.87 g) was in Swarna Sheetal variety in winter grown crop. Under protected (naturally ventilated poly house), Solan Srijan variety recorded maximum fruit weight (247.33 g) in summer season grown crop compared to Swarna Sheetal variety (199.89 g). This could be due to the genetic trait of individual variety and also optimum temperature and humidity in polyhouse condition. Bisht et al (2010), Hossain et al (2010) and Kumar (2014) also reported the similar findings. Under open field environmental condition, the maximum in yield per plant (1.28 kg) and yield per ha (23.46 t/ha) was in Solan Srijan variety of summer season grown crop and the lowest yield per plant (0.71 kg) and yield per ha (16.68 t/ha) was in winter season crop of Swarna Sheetal variety. Protected (naturally ventilated poly house) grown crop given maximum yield in two seasons compared to open field condition. The maximum yield per plant (2.44 kg) and yield per ha (44.73 t/ha) was in Solan Srijan of summer season grown crop. The increased yield under protected condition might be related to superior crop performance in terms of several yield contributing characters such as per cent fruit set and the number of fruits per vine in polyhouse (Fig. 2). Rajasekar et al (2013) also reported that protected cultivation recorded increased yield in many vegetables including cucumber.

Biochemical parameters: The maximum content of TSS (3.79 ^{0}Brix) was recorded in Solan Srijan variety under protected in summer season compared to winter season (3.33 ^{0}Brix). In open environmental field 3.42 ^{0}Brix of TSS content was in Solan Srijan variety in summer season crop. These results were in accordance with the findings of Chandra et al (2003) under protected condition, while Cantore et al (2008), Ahmet and Vedat (2009) reported under open field condition. Solan Srijan variety had maximum (4.49 mg/100 g) content of ascorbic acid in winter season under protected grown environmental condition and in open field grown environmental condition, Solan Srijan variety had the maximum ascorbic acid (4.36 mg/100 g) content in winter season. The reduction in ascorbic acid is due to the formation of dehydro ascorbic acid by the ascorbinase enzyme. The above research results are in full agreement with the earlier work of Thangam and Thamburaj (2008) and Caliman et al (2010) under greenhouse condition and Kumar et al (2007) reported similar observations under open grown condition. Acidity values differ from season to season. The maximum

Table 1. Mean values of weather variables (crop period) recorded during summer and winter seasons

Growing conditions	Temperature (^{0}C)				Relative humidity (%)			
	Summer		Winter		Summer		Winter	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Open	34.8	29.3	27.8	21.4	79.5	67.4	62.4	59.3
Protected	38.5	31.6	28.3	22.3	91.4	74.8	71.6	63.4

Table 2. Impact of seasonal variations and growing conditions on fruit length, diameter and volume attributes of cucumber varieties

Varieties	Fruit length (cm)				Fruit diameter (cm)				Fruit volume (cm^3)			
	Open		Protected		Open		Protected		Open		Protected	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Solan Srijan	19.56^a	17.90^{ab}	20.06^a	17.99^{ab}	3.56^{ab}	3.43^{ab}	3.66^{ab}	3.46^c	163.66^c	159.66^c	184.87^a	176.93^{ab}
Swarna Sheetal	16.66^{ab}	15.43^c	17.83^{ab}	16.81^{ab}	4.43^a	4.21^a	4.53^a	4.24^a	176.33	174.54^{ab}	183.51^a	181.56^a

Table. 3. Impact of seasonal variations and growing conditions on yield attributes of cucumber varieties

Varieties	Fruit weight (g)				Yield per plant (kg)				Yield per hectare (t/ha)			
	Open		Protected		Open		Protected		Open		Protected	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Solan Srijan	241.03^a	234.26^a	247.33^a	233.52^a	1.28^{ab}	1.23^{ab}	2.44^a	2.31^a	23.46^{ab}	22.54^{ab}	44.73^a	43.81^a
Swarna Sheetal	182.22^{ab}	174.87^c	199.89^{ab}	191.89^{ab}	1.13^{ab}	0.71^c	2.24^a	2.18^a	17.04^c	16.68^c	42.06^a	38.96^a

Table 4. Impact of seasonal variations and growing conditions on quality attributes of cucumber varieties

Varieties	Total soluble solids (^{0}Brix)				Ascorbic acid (mg/100 g)				Acidity (%)			
	Open		Protected		Open		Protected		Open		Protected	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Solan Srijan	3.42^{a}	3.16^{a}	3.79^{a}	3.33^{a}	4.36^{a}	4.21^{a}	4.11^{a}	4.49^{a}	0.39^{a}	0.33^{a}	0.33^{a}	0.31^{ab}
Swarna Sheetal	3.08^{ab}	2.98^{c}	3.13^{ab}	3.11^{ab}	3.33^{ab}	3.13^{c}	3.43^{ab}	3.06^{c}	0.29^{ab}	0.26^{c}	0.40^{a}	0.37^{a}

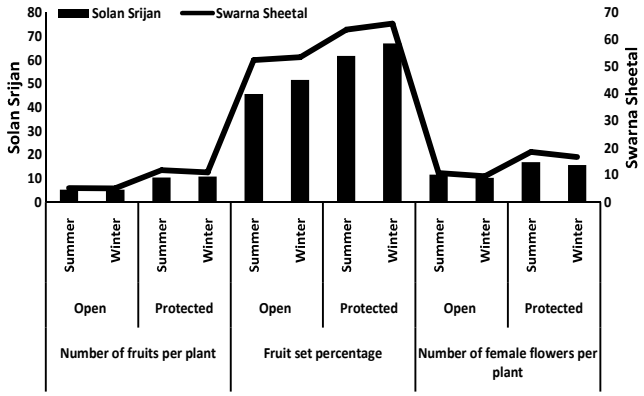


Fig. 2. Effect of growing conditions and seasonal variations on flowering parameters of cucumber varieties

acidity content (0.40%) was recorded in Swarna Sheetal variety under protected in summer season. In open field environment condition maximum acidity (0.39 %) was recorded in Solan Srijan variety in summer season. The reduction in acidity might be attributed to the chemical interactions between the organic constituents of the pulp induced by temperature and the action of different enzymes. Similar findings were also reported by Ahmet and Vedat (2009) reported under open-field conditions.

CONCLUSION

Weather factors such as temperature, relative humidity and rainfall plays a major role in the production of cucumber. The maximum temperatures recorded in the summer season under the protected condition. It influences the maximum yield compared to open condition. Solan Srijan variety given longer fruits as well as maximum yield compared to Swarna Sheetal variety. The above investigation proved that cucumber as a summer season vegetable crop and its given maximum vegetative growth, yield and quality in summer season under protected condition.

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Phenological and Floral Variations in *Moringa oleifera* Ecotypes for Reproductive Adaptations in Subtropical Conditions

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***Abstract*:** *Moringa oleifera* is an important medicinal tree valued for its highly nutritious pods. It is widely distributed in tropics and native to foothills of Himalayas. The present study aimed to assess the phenological and floral studies of landraces and high-yielding ecotypes of *Moringa oleifera* procured form diverse agro-ecological zones of Indian subcontinent. The observations revealed significant variation in timing of occurrence of different phenophases in these ecotypes. The ecotypes of subtropical origin initiated vegetative and floral bud events relatively earlier than those from tropical, arid and semi-arid regions. Ecotype S1 (*Bhagya*) was found potentially viable ensuring pollination and post fertilization success due to long petal size and less filament length. Higher pollen viability and *in-vitro* germination with more pollen size was observed in S7 ecotypes, which could be exploited for future breeding programmes. Differences were found non-significant for days taken to flower anthesis, anthers dehiscence, pollen shape and visitation of pollination vectors noticed during flowering. The study revealed greater climate resilience and reproductive success in ecotypes of *M. oleifera* by their unique floral and pollen traits. In addition, the ecotypes exhibited variation in growth and morphological characteristics that are deemed as potentially beneficial silvicultural traits for adoption in agroforestry systems.

***Keywords*:** *Moringa oleifera,* Ecotype, Phenology, Floral biology, Reproductive adaptation

Moringa oleifera Lam., is a member of the monogeneric family *Moringaceae* and genus has 13 species, of which *M. oleifera* is widely cultivated in tropical and subtropical world. *Moringa oleifera* is considered to have its origin in foothills of Himalayan region (Lalas et al 2012) but nowadays distributed in Asia, the Arabian peninsula, East and West Africa, and some part of American countries (Mishra et al 2011) owing to its rapid growth, drought tolerance, and wider adaptability. It grows best in temperatures ranging from 25°C to 35°C (Thurber and Fahey 2009). Flowering period varies widely depending on the variety and the location and usually flowers once a year but can flower twice in more tropical part of the world. In regions with no change of temperature or precipitation throughout the year, flowering may be more or less continuous. In India, the flowering occurs between March to May, in Moreno, Buenos Aires Province, Argentina, the flowering period is between November and March but some flower were differentiated on plants grown in greenhouse during June (Thiberge 2014). For effective production of immature fruits and seeds, appropriate pollination and fertilization techniques are required which depends upon flower dimensions and pollen characteristics. Extremely low fruit low fruit set rates, *i.e.* 1.5% in dry and 0.31% in the rainy season have been reported as compare to its abundant floral display; the reason for its less fruit set are still unknown (Krieg et al 2017). The slight change in environment conditions leads to the disruption of flower morphology followed by pollen viability and stigma receptivity, fruit setting and pod percentage (Radice and Giordani 2018). The drumstick tree is a mixed mating species adapted for out-crossing, although it is also possible to self-cross (Muluvi et al 2004). Keeping in view of above facts and discrepancies, the present study had been planned to acquire the detailed knowledge about its phenological behaviour, flower morphology and floral studies of among landraces and cultivated varieties comparing with the sub-tropical or regional ecotypes of *Moringa oleifera* for floral adaptation in subtropical conditions of north western India.

MATERIAL AND METHODS

Climate and plant material: The experiment was conducted at Punjab Agricultural University, Ludhiana. The experimental site is located at an elevation of 247 m amsl (30°54´N latitude and 75°48´E longitude). The area falls in the central plain agro-climatic zone of Punjab. The region is categorized by sub-tropical environment. In May to June and in December to January, the region has hot summer and severe winter. The coldest temperature might fall up to 4°C or even below, and in the summer time the maximum temperature might rise to more than 46°C. It is not usual to

get frost. The land is deep, well drained, granular, low humus textured loam. The soil's pH is neutral. The average yearly rainfall is 760 mm and during June and September around three-fourth of this year's south-west monsoon. The meteorological data during the study period (2020 to 2021) has been depicted in Figure 1 and 2. In the present study, eight ecotypes were used for phenological and reproductive biology studies. Seed of four promising varieties adopted at national level and three local germplasm of *Moringa oleifera* were procured from different states of India, and one wild ecotype (S4) maintained at PAU, Ludhiana was used as check source (Table 1). The evaluation trial was established since August 2017 at spacing of 3.5×2.0 m in three replications with plot size of 5 plants/treatment following complete randomized block design.

Field and laboratory observations: Plants were pollarded at 6 feet height to avoid the breaking damage due to having very soft wood. Phenological observations like growth habit, leaf retention period, functional type (Singh and Kushwaha 2005), vegetative bud swell and burst; and reproductive traits like floral bud swell and burst, flowering span and days to anthesis were taken on five branches selected on three trees with three replications. Bud characteristics were measured for two consecutive years, 2019-20 and 2020-21, while remaining phenological and reproductive traits were recorded only in 2021. Flower morphological characteristics, *i.e.* number of flowers per panicle, peduncle and pedicle length (cm), flower length and width (cm), sepal length (mm), petal length (cm), filament and style length (cm) were recorded on 15 flowers per replication. The mode of anther dehiscence was carefully observed and recorded for seven seed source, namely, S1, S2, S3, S4, S7, S9 and S10. For this observation, flowers from each seed source was taken and observed from floral bud burst to complete development of flower and time of anther dehiscence was recorded. The activities of flower visitors/pollinators were carefully watched and identified with the help of the Department of Entomology, PAU, Ludhiana, throughout the flowering period.

Pollen and stigma studies: Pollen viability was tested using 2% acetocarmine dye. The ocular micrometre was standardised with the stage micrometre to analyse pollen morphology. Under the electron microscope, the shape/form of the pollen was studied. The *in vitro* germination of pollen extracted from different sources was tested immediately after collection. Freshly collected pollen were tested to check it's *in vitro* germination using five different growing media, *viz*., 5, 10, 15 and 20% sucrose and 200 microgram/ml boric acid for all sucrose combinations along with distilled water as control treatment. Stigma receptivity was visually observed of stigmatic surface. From 24 hours before the opening of flower till it wilted completely, the stigma's appearance was continuously observed. The stigma was considered receptive when stigma exude white watery substance and the colour of stigma changes from greenish white to pinkish white, whereas dark brown or black coloured of stigma was accounted non-receptive.

Statistical analysis: The mean data recorded on various observations (phenological and reproductive parameters) were subjected to statistical analysis with the help of SPSS *version* 21 software.

RESULTS AND DISCUSSION

Phenological behaviour: Phenological events are the result of internal factors such as biorhythms, which are regulated by the genetic constitution of the species and environmental factors (Orlandi et al 2007). The significant differences were observed for the time of occurrence of phenological events which might be due to the wide variations in local environmental conditions (Fig. 1, 2). Ecotypes S7, S9, S1 and S2 are evergreen in their respective original habitat while their functional type was found to change in subtropical conditions (Table 1, 2). All ecotypes showed a high vegetative seasonality showing three patterns in functional type, three types of growth habit. The leaves of the south Indian ecotypes showed burnt symptoms in January due to chilling temperature and remain leafless till mid-March, while local source (S4) does not have any leaf burning symptoms during winter months. Their leafless nature may be varying with original locality but the changes in their functional type are due to G×E interactions (Singh and Kushwaha 2005, Sauvadet et al 2021).

The significant differences were observed in mean number of days taken for vegetative growth, bud characteristics, and days to anthesis among the eight ecotypes (Table 3). Vegetative bud growth was concentrated from 2nd fortnight February to 1st fortnight of November. Ecotype S11 was first to be noticed for swelling its vegetative buds in 3rd week of February in 2020, while S4 was first noticed in 2nd week of February in 2021 which was almost 17 days week earlier than 2020 (Fig. 3) as it is adapted to prevailing environmental conditions. However, bud initiation was observed only 2-6 days earlier in procured ecotypes under subtropical climate. The minimum number of days took from vegetative bud swelling to bud bursting was observed in subtropical local source (11 and 15 mean days) for both years, while maximum (25 and 24 mean days) were observed in semi-arid sources S1 and S11 followed by tropical sources, namely, S7 (24 days) and S2 (22 days) (Fig. 4). Vegetative bud swelling was advanced by at least 3 days to 17 days in 2021 than 2020. This could be due to the mean

maximum temperature in 2021 was higher in February and very less precipitation occurred in winter months of 2020. The buds began to break early due to an early increase in threshold temperature (the temperature required for swelling and bursting). The differences in time of occurrence of vegetative bud swelling and bursting between 2020 and 2021 was very less in majority of ecotypes, which reflects that the ecotypes are adapted under subtropical conditions (Fig. 3, 4). More precipitation in September and October 2021, vegetative bud swelling and bud bursting span was found to be increased by 4 and 6 mean days in *Moringa* ecotypes, respectively. The increase in temperature affects more S4 for vegetative bud swell and S7 for bud burst span in 2021. The findings accord with Orlandi et al (2007) in *S. Acutifolia*.

The change from vegetative to reproductive growth is triggered by environmental variables. Mean flowering peak was seasonal and genotypically controlled, with similar flowering patterns for both years, and differences in date of occurrence of the phenophases among ecotypes (Table 3). The floral bud swelling comparatively delayed (2nd fortnight of March 2020) in subtropical ecotype (S4) which is closely followed by S9 tropical ecotype (Fig. 5). However, it was observed 30 mean days (2nd fortnight of February 2021) earlier in S4 during environmental conditions of 2021. Ecotypes S1, S2, S7 and S9 showed floral bud swelling two times in 2020 and 2021 as they showed flowering twice in a year. The time taken from floral bud swell to bud burst was minimum in S1 semi-arid ecotype (11 mean days) during 2020 and 2021. However, maximum was in S4 (18 mean days) (Fig. 6). The significant differences were observed for duration of floral bud swelling span which was continued for 49.75 and 45.75 mean days in 2020 and 2021, respectively (Table 3). The bud bursting span was 51.75 and 48.50 mean days in 2020 and 2021, respectively. Thus, the floral bud swelling and bud bursting span was found increased by 2 and 3 mean days in 2021. Data pertains to flower anthesis revealed that maximum anthesis period was observed in S2 and S7 (26 mean numbers of days), while minimum was noticed in S11 (23.00 mean days).

The change in weather conditions has less effect on

Table 1. Details of *Moringa oleifera* ecotypes procured from geographical origin

Agro-climatic zone	Code	Identity	Ecotype (CL/LR)	Geographical origin	Latitude (°N)	Longitude (°N)	Altitude (m)
Tropical region	S9	*ODC-3*	Cultivar	Indian Agri Farm, Tamil Nadu	8.15	77.59	31
	S7	*PKM-1*	Cultivar	Tamil Nadu Agricultural University, Tamil Nadu	11.31	76.93	310
	S2	*Konkan Ruchira*	Cultivar	Dr. Balasaheb Sawant Konkan Krishi Vidypeeth, Dapoli, Maharastra	17.75	73.18	164
Subtropical region	S4 (Check)	PAU-1	Landrace	Ludhiana, Punjab	30.90	75.81	247
Semi-arid region	S1	*Bhagya*	Cultivar	University of Horticulture Science, Bagalkot, Karnataka	16.18	75.69	542
	S11	Mandya local	Landrace	Mandya, Karnataka	12.52	76.89	683
Arid region	S3	Dantiwara local	Landrace	Sardar Krushinagar Dantiwada Agricultural University, Gujarat	25.24	73.32	311
	S10	CAZRI, local	Landrace	ICAR-CAZRI, Jodhpur, Rajasthan	26.25	72.99	236

Note: CL – Cultivar; LR – Landrace

Table 2. Start and end dates of leaf retention and leafless phenophase in *Moringa oleifera* ecotypes

Moringa ecotypes	Growth habit	Leaf retention period		Leaf less period		Functional type
		Start	End	Start	End	
S9	Compact	20-Mar-20	10-Jan-21	11-Jan-21	11-Mar-21	Fully deciduous
S7	Compact	18-Mar-20	15-Jan-21	16-Jan-21	10-Mar-21	Fully deciduous
S2	Compact	Throughout year		No		Semi-deciduous
S4	Erect	Throughout year		No		Evergreen
S1	Compact	21-Mar-20	10-Jan-21	11-Jan-21	12-Mar-21	Fully deciduous
S11	Intermediate	16-Mar-20	18-Jan-21	19-Jan-21	14-Mar-21	Fully deciduous
S3	Intermediate	Throughout year		No		Semi-deciduous
S10	Intermediate	Throughout year		No		Semi-evergreen

regional ecotypes than local one and might be due to their rigid phenological behaviour. Floral bus set time was observed earlier in 2021 (Fig. 5, 6) but bud swell and burst span was found to be increased with increasing mean temperature (Table 3). Time taken for bud bursting was found decreased due to increase in temperature in 2021. Thus, increasing temperature may be favourable for floral adaptation in procured ecotypes. The minimum effect of increasing temperature in 2021 was observed in S11 ecotype (3 mean days earlier). It was due 2°C-5°C more day and ~2°C more night temperature in February and March 2021 (Fig. 1 & 2). Variation in floral bud swelling and bursting are in agreement with finding of Radhamani et al (1993) on reproductive biology and breeding system studies in *Tamarindus indica*. Similar trends of findings were reported by Pant et al (2003) on *Grewia optiva,* Wani (2005) on *Bauhinia variegata* and Chauhan et al (2009) on *Dalbergia sissoo*. The delay in bud swelling and its bursting may be attributed to the climatic factors as such as temperature and rainfall. During 2020 the occurrence of comparatively cooler

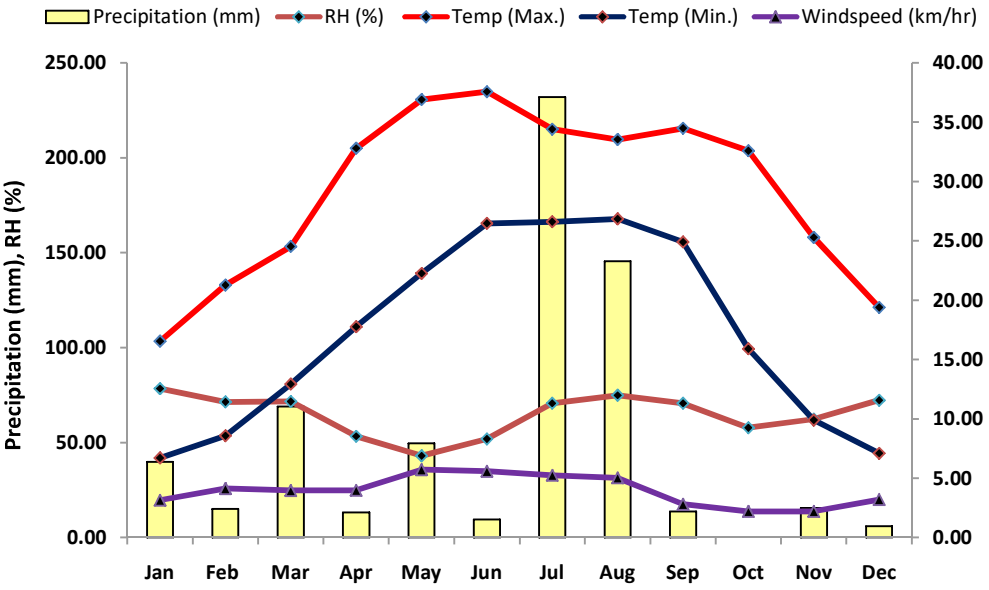

Fig. 1. Mean monthly meteorological parameters of experimental site during 2020

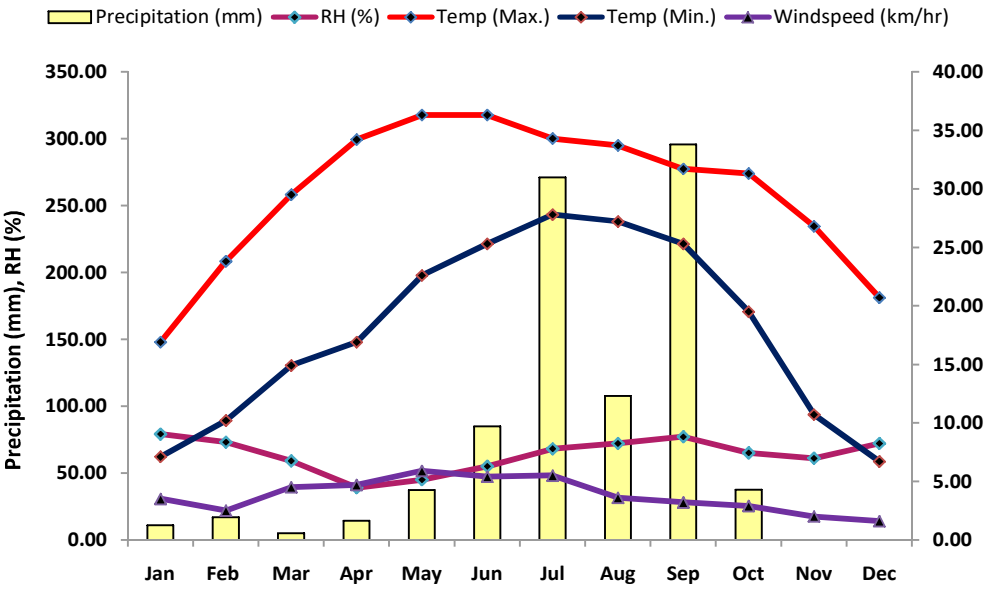

Fig. 2. Mean monthly meteorological parameters of experimental site during 2021

winter along with less precipitation may have delayed the phenological events.

Flower morphology: The ecotypes showed significant differences in the floral morphometric characteristics (Table 4). Maximum number of flowers per panicle was observed in S7 (93 flowers per panicle) and all ecotype showed higher flowers per panicle than local ecotype (78 flowers per panicle) with the average of 85.38 flowers per panicle. The number of flowers was higher in regional ecotypes than the check ecotype with the mean value of number of flowers per panicle (85.38 flowers per panicle) and similar with the studies of Raja et al. (2013) in *M. oleifera* grown in semiarid and arid ecosystem. The average length of peduncle and pedicel were 1.55 and 1.83 cm, respectively. Ecotype S7 (1.99 cm) had more peduncle length than the check ecotype S4 (1.81 cm), which is preferable to avoid the space competition with simultaneously occurred vegetative flush growth as described by Singh et al. (2021). Less pedicel length is best to reduce the flower drop as observed in majority of ecotypes except S10 and S7 ecotype. Flower width was found higher in almost all ecotypes than check source which is directly correlated with the petal length and is preferred for pollination visitors to provide the sitting space for pollinator insect. Filament length was almost lesser than the check source and no specific pattern was for the style length. Thus,

Table 3. Variation in mean number of days for different phenophases in *Moringa oleifera* ecotypes and their flowering span during the years 2020 and 2021

Moringa ecotypes	Leaf retention period	Leaf less period	Vegetative bud swell span		Vegetative bud burst span		Floral bud swell		Floral bud burst		Days to anthesis 2021	Flowering span	
			2020	2021	2020	2021	2020	2021	2020	2021		2020	2021
S9	296	59	252	253	237	247	48	57	43	54	25.00	April-May & Aug-Oct	April-May & Sep-Oct
S7	303	53	248	257	235	248	50	52	46	47	26.00	April-May & Oct-Dec	April-May & Oct-Nov
S2	365	0	234	235	225	231	52	51	49	49	26.00	April-May & Sep-Oct	April-May & Aug-Oct
S4	365	0	227	239	226	235	47	54	39	52	25.00	April-May	March-May
S1	295	60	254	253	240	244	49	55	48	52	24.00	April-May & Sep-Oct	March-May & Aug-Oct
S11	308	54	246	256	236	242	51	46	47	42	23.00	April-May	April-May
S3	365	0	250	244	238	234	50	55	48	52	25.67	April-May	April-May
S10	365	0	240	245	232	239	51	44	46	40	24.33	April-May	April-May
Mean	332.75	28.25	243.88	247.75	233.63	240.00	49.75	51.75	45.75	48.50	24.88	-	-
CD (p=0.05)		-	6.57	5.52	5.94	5.37	4.36	4.04	4.84	4.42	4.27	-	-

Table 4. Vegetative and reproductive morphometric variability among 8 ecotypes of *Moringa oleifera*

Moringa ecotypes	Number of flowers per panicle	Peduncle length (cm)	Pedicel length (cm)	Flower length (cm)	Flower width (cm)	Sepal length (mm)	Petal length (cm)	Filament length (cm)	Style length (cm)
S9	83.00	1.20	1.69	1.78	2.47	2.38	1.39	0.42	0.29
S7	93.00	1.99	2.02	2.07	2.85	3.05	1.63	0.43	0.28
S2	87.00	1.47	1.81	1.84	2.56	2.57	1.37	0.45	0.36
S4	78.00	1.81	1.92	1.85	2.43	2.79	1.41	0.53	0.30
S1	85.33	1.51	1.53	1.96	2.45	2.95	1.69	0.40	0.33
S11	84.33	1.81	1.63	1.71	2.49	2.57	1.30	0.40	0.29
S3	90.67	1.25	1.92	1.83	2.62	2.68	1.42	0.41	0.33
S10	81.67	1.32	2.08	1.89	2.43	2.49	1.50	0.54	0.29
Mean	85.38	1.55	1.83	1.87	2.54	2.69	1.46	0.45	0.31
CD (p=0.05)	8.05	0.66	0.35	0.15	0.28	0.05	0.14	0.05	0.03

ecotype S1 was observed best among *M. oleifera* seed sources due to having more petal length and less difference between filament and style length which is desired for optimum pollination and higher rate of fruit setting. Thus, we found that geographical origin and prevailing environmental factors does not have any significant effect on flower morphology and dimensions among ecotypes. However, the ecotypes originated in the different habitats but did not have more difference in their floral characteristics and dimensions as compare to local ecotype. This differences between ecotypes are not expected as ecotypes of the same species (*Moringa oleifera*) would have similar floral characters because ecotypes are more ecologically similar (Burns and Strauss 2011). But the time of occurrence of phonologically events have changed due to G×E interaction.

Pollen and stigma: Flower anthesis is of a forenoon pattern (6.00 hrs to 13.30 hrs) after which pollen anthesis and nectar secretion take place (Table 5). The maximum dehiscence of anthers took place between 6:00 am to 12:00 pm, of which peak dehiscence was observed in between 8:00 am to 9:00 am. Similarly, maximum anthesis and pollen dehiscence in morning hours by observed by Pant et al (2003) in *Grewia optiva*, Chowdhuri et al (2004) in *Morus*, Wani (2005) in *Bauhinia variegata* and Chauhan et al (2009) in *Dalbergia sissoo*. Pollen quality is clearly a critical factor in pollination success and the method employed in collecting, storing and testing. The pollen viability percentages of freshly collected pollen were significantly affected by the climatic conditions. In 2021, the maximum viability (93%) was in S7 ecotype followed by S2, S10 and S3, while minimum (78%) pollen

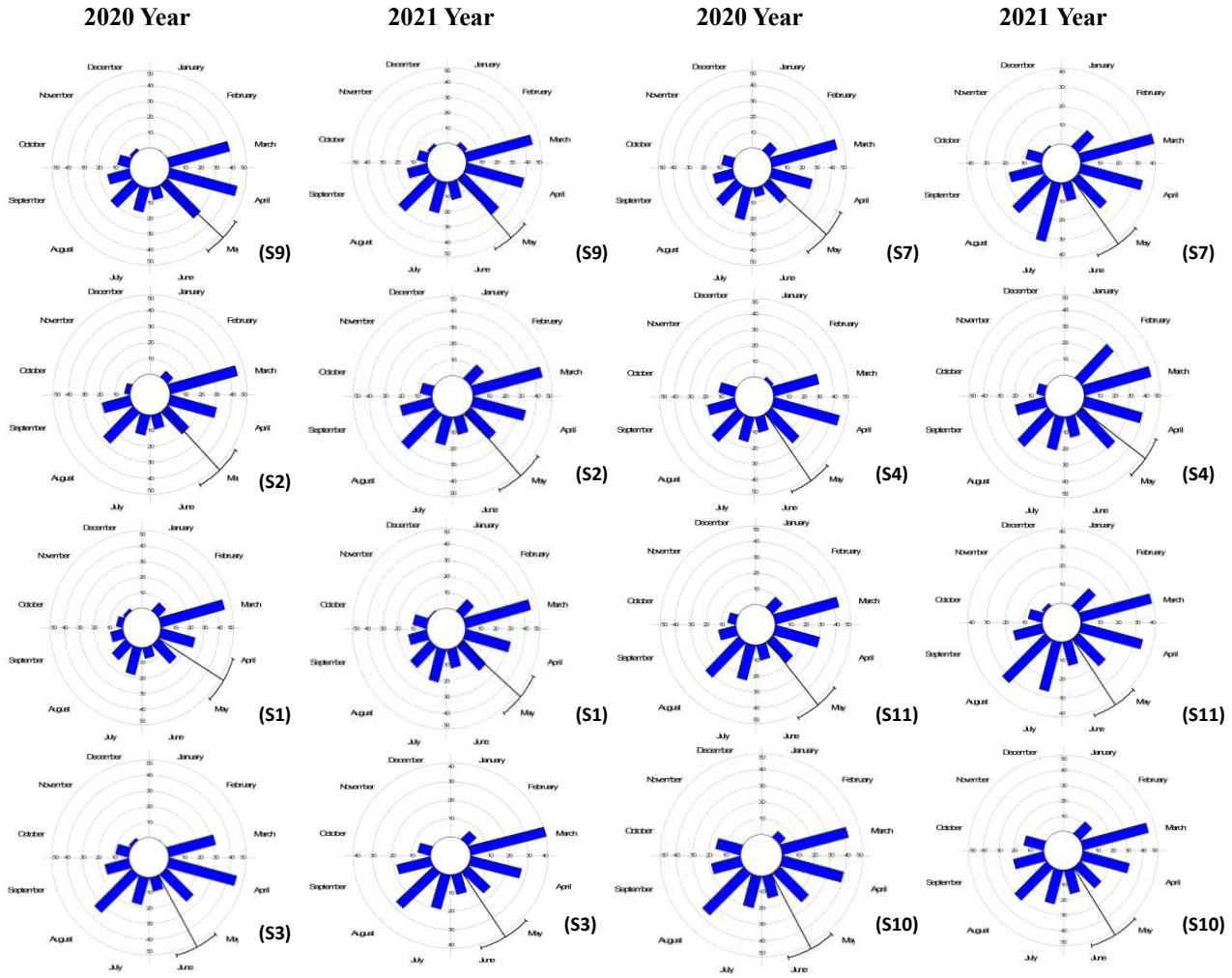

Fig. 3. Circular histograms depicting frequency of vegetative bud swelling dates of *Moringa oleifera* in subtropical climate of north-west India during 2020 and 2021. Bars represent monthly frequency of occurrence an event (vegetative bud swelling) in 45 tagged branches of *M. oleifera* for each year. The line indicates mean seasonal intensity of an event with standard errors

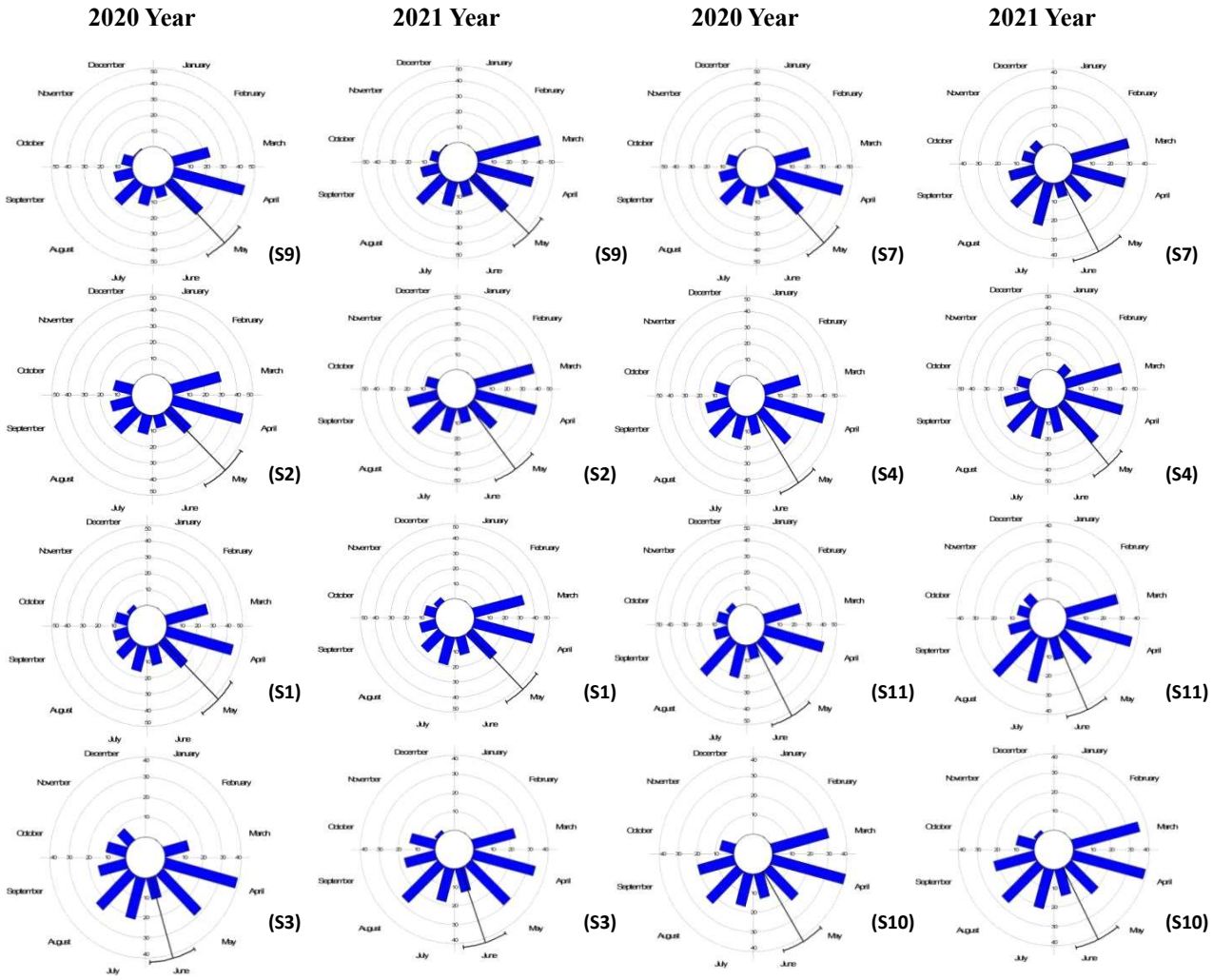

Fig. 4. Circular histograms depicting frequency of vegetative bud bursting dates of *Moringa oleifera* in subtropical climate of north-west India during 2020 and 2021. Bars represent monthly frequency of occurrence an event (vegetative bud bursting) in 45 tagged branches of *M. oleifera* for each year. The line indicates mean seasonal intensity of an event with standard errors

Table 5. Variation in timing of anther dehiscence and pollen studies among different *Moringa oleifera* ecotypes

Moringa ecotypes	Anthers dehiscence	Pollen viability (%) ± SEm	Pollen size (µm)	Pollen germination (%)			
				T2	T3	T4	T5
S9	6.00 hrs-12.30 hrs	80±1.15	45.30×40.23	28±1.15	78±2.31	69±1.15	64±1.15
S7	6.00 hrs-12.00 hrs	93±1.15	46.32×41.05	35±1.15	90±1.15	81±0.58	77±1.15
S2	7.30 hrs-12.30 hrs	88±1.15	43.50×39.45	35±1.15	84±2.31	77±1.15	70±1.15
S4	7.00 hrs-12.00 hrs	78±1.15	47.23×41.12	25±0.58	75±1.73	70±1.15	69±0.58
S1	6.30 hrs-12.00 hrs	80±1.73	45.32×40.18	30±0.58	76±1.73	70±0.58	64±2.31
S11	6.30 hrs-13.00 hrs	82±1.75	46.24×40.87	28±1.51	81±1.24	76±1.41	70±1.42
S3	6.30 hrs-13.00 hrs	83±1.73	46.12×40.65	29±1.73	80±1.15	75±1.73	72±1.15
S10	7.00 hrs-12.30 hrs	85±1.15	44.89×39.86	32±1.15	82±1.15	74±1.15	68±1.15
Mean±Sem	-	83.63±1.35	45.62×40.43	30.25±1.05	80.75±1.85	74.00±1.20	69.25±1.32

Concentration of solution used for pollen germination was 0% (T1), 5% (T2), 10% (T3), 15% (T4) and 20% (T5) sucrose + 200 microgram/ml boric acid.
NO pollen germination was observed in treatment T1 (without sucrose). , Pollen shape, i.e. prolate spheroidal to sub prolate is same in all ecotypes

was observed for S4 local ecotype. Similarly, high percentages (>70%) were earlier recorded by Bhattacharya and Mandal (2004) in *M. oleifera*. The maximum pollen size (47.23×41.12 µm) was in S4 local source followed by pollen S7, S3, S1 and S9 source. Minimum pollen size 43.50×39.45 µm was recorded for S2 source. The pollen size was found to less in subtropical conditions than the *M. oleifera* grown in tropical climate (Bhattacharya and Mandal 2004). Pollen shape was found unaffected by the environmental factors and genotype. All ecotypes had similar type of pollen shape, *i.e.* prolate spheroidal to sub prolate. However, Jyothi et al (1990) reported spheroidal shape pollen grains with (~35 µm) pollen size.

It was excepted that any differences in pollen traits between ecotypes would be seen as in smaller values than local adaptive ecotype of subtropical habitat because of variable weather parameters. However, pollen viability and *in vitro* pollen germination in regional ecotypes were higher in the subtropical habitat. On the other side, pollen size was less than the local cultivar. These pollen traits may be effective for the successful pollination and fertilization under varying level of environment. The mean maximum pollen germination (80.75%) was observed @ 10% sucrose +200 microgram/ml boric acid followed by 15% 20% and 5% sucrose solutions and no germination was recorded for distilled water alone. Pollen germination percentage varied

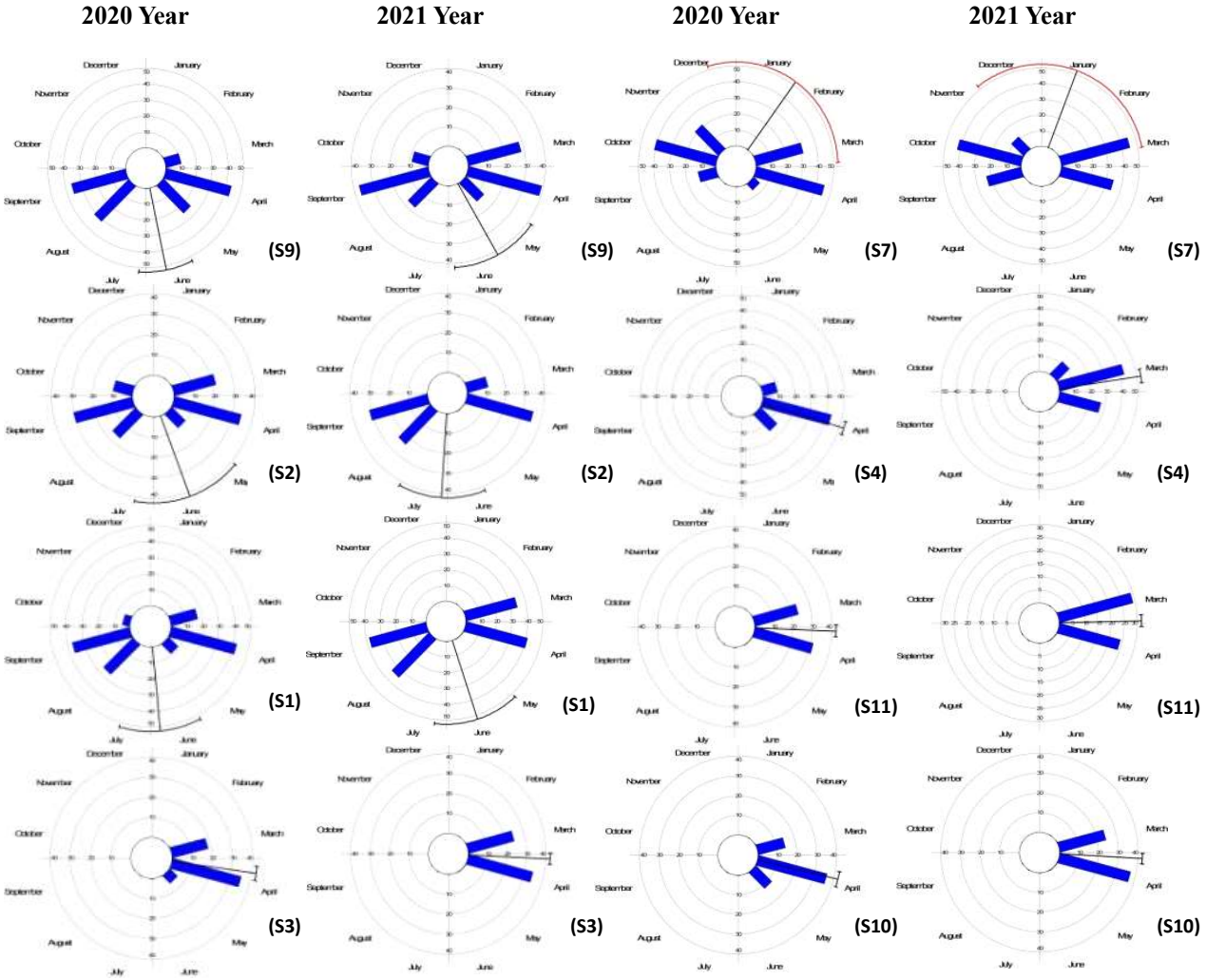

Fig. 5. Circular histograms depicting frequency of floral bud swelling dates of *Moringa oleifera* in subtropical climate of north-west India during 2020 and 2021. Bars represent monthly frequency of occurrence an event (floral bud swelling) in 45 tagged branches of *M. oleifera* for each year. The line indicates mean seasonal intensity of an event with standard errors

between 75-90% @ 10% sucrose + 200 microgram/ml boric acid solution which was higher than S4 local ecotype (Table 5). Pollen grains of S7 source recorded maximum germination (90%) in solution of 10% sucrose supplemented with 200 microgram/ml boric acid followed by S2 (84%), whereas minimum pollen germination percentage (75%) was observed for S4. The present investigations are in agreement with results of Bhattacharya and Mandal (2004) on *M. oleifera* and they reported 94% in vitro pollen germination. Receptivity of stigma is a critical factor governing success of intra- and inter-specific hybridization in dioecious species like *Moringa oleifera*. In order to study the stigma receptivity by visual observation, stigma of different age groups *viz*., 24, 48 and 72 hours after anthesis were observed. The, stigma was considered receptive when the lobes of stigma became fully shining and watery white in colour. The stigmas became receptive between 48 to 72 hours after anthesis. Stigma receptivity among ecotypes varied from three to five days under subtropical climate. Similar observation were reported by Bhattacharya and Mandal (2004) in *M. oleifera*, Pant et al (2003) on *Grewia optiva*, Wani (2005) on *B. variegata* and Chauhan et al (2009) in *D. sissoo*.

Pollination: *Moringa oleifera* is generally insect pollinated plant but combination of insect and wind pollination (Ambophily) had been observed in all *M. oleifera* ecotypes. These insects visited the flowers all the day but maximum activity was observed between 7.00 am to 10.00 am which coincided with the pollen shedding and anthesis period. No

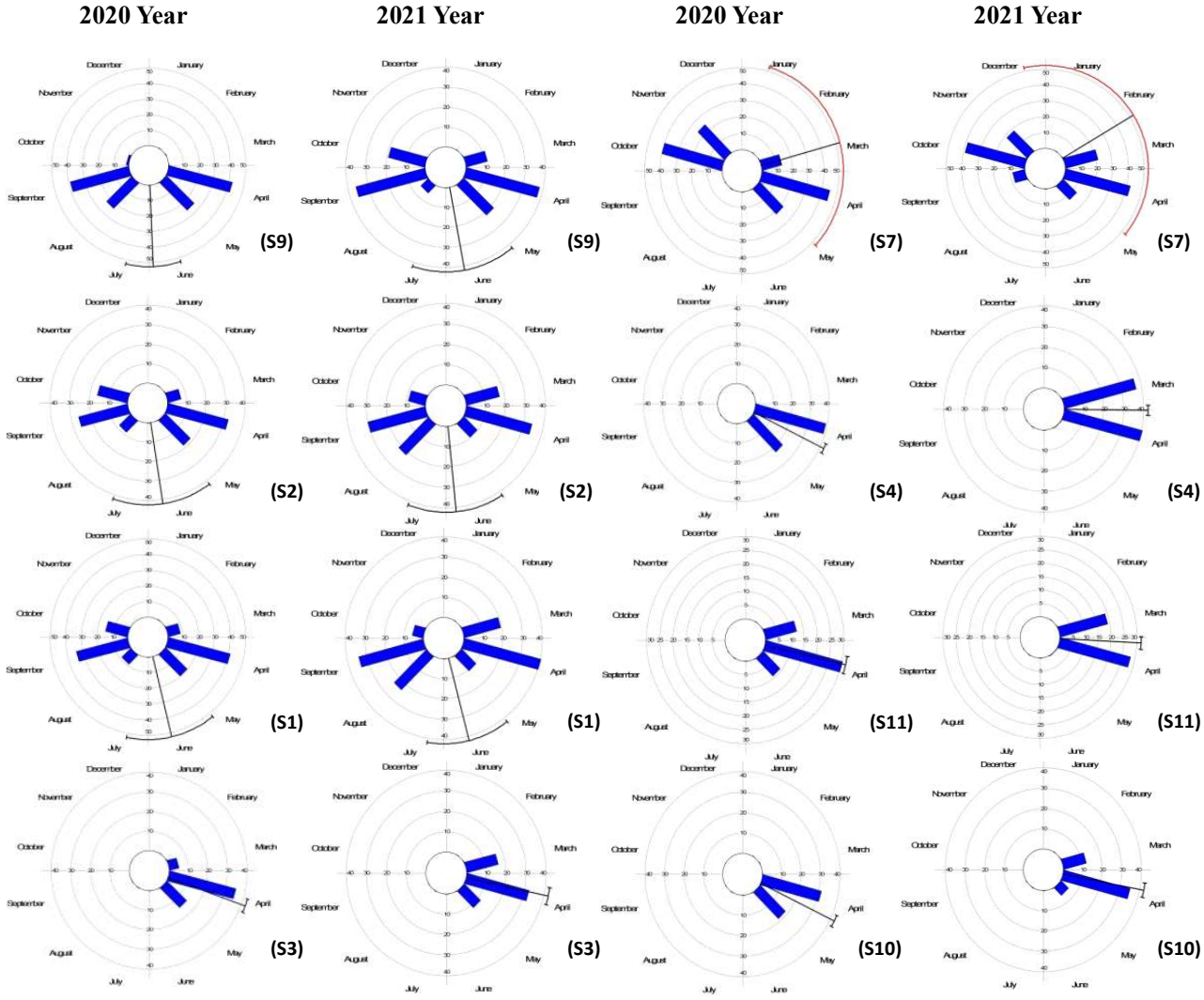

Fig. 6. Circular histograms depicting frequency of floral bud bursting dates of *Moringa oleifera* in subtropical climate of north-west India during 2020 and 2021. Bars represent monthly frequency of occurrence an event (floral bud bursting) in 45 tagged branches of *M. oleifera* for each year. The line indicates mean seasonal intensity of an event with standard errors

clear difference was observed for the selection or preference of particular ecotype. It might be due to similar chemical composition of *Moringa* flowers which is tightly linked with the genetics of plant. The close examination of the mode of pollination revealed that pollen grain sticks to different parts of their body *viz*., abdomen, mouth parts, legs, etc. The visitors affecting cross pollination in *M. oleifera* were western honey bees (*Apies mellifera*), carpenter bee (*Xylocopa* spp.), stingless bee (*Meliponini* spp.), common fruit flies (*Drosophila melanogaster*), wasps (*Polister* spp.) and bumble bee (*Bambus* spp.). Besides, blister beetle (*Mylabris phalerata*), aphids (*Aphis gossypii*), black tree hopper (*Enchenopa binotata*), carpenter ants (*Camponotus* spp.), lady bird beetle (*Coccinellidae* spp.), sun bird (*Leptocoma* Aspasia), Indian myna (*Acridotheres tristis*), Indian palm squirrel (*Funambulus palmarum*) and rose-ringed parakeet (*Psittacula krameri*), of which, flies, wasps, honey bees and bumble bees were the main pollen pollinators. In *Moringa* ecotypes, flowering continues for one and half month and simultaneously development of sweet tinny pods has started. Due to high nutritious pods, large birds and small animal were also spotted on *Moringa* plants. When they climb or jump between branches may carry forward the pollen grains with their body parts and act as a pollinator (Singh et al 2021).

CONCLUSIONS

This is the first report of testing the climate-induced phenological response and reproductive performance of *Moringa oleifera* cultivars and landraces native to tropical, arid and semi-arid agro-ecological regions and grown under subtropical climate of Punjab. Their functional type, growth habit, time of initiation of phenological events, flower morphometrics and pollen characteristics revealed distinct variation induced by seasonal changes in temperature and rainfall pattern as they realized in their native habitat. Vegetative and floral bud characteristics advanced by at least 3 days to 17 days in 2021 than 2020, attributed due to the fluctuation in temperature in spring season and precipitation in winter season. Wider flower dimensions and quality pollen traits in var *PKM-1* (tropical region) and var *Bhagya* (semi-arid region) showed its potentiality for yielding nutritive flowers and pods twice in a year that will likely raise its demand for culinary purposes. Thus, phenological rigidity (earliness of flowering and fruiting) in the evaluated ecotypes will likely strengthen the future breeding strategies in *Moringa oleifera* and had future prospects for promoting climate resilient food production system.

AUTHORS CONTRIBUTION

Conceptualization and designing of the research work (AKD; GPSD); Execution of field/lab experiments (MS, AKD, SS); Data collection (MS); Analysis of data and interpretation (GSW, AKD, RK); Writing - original draft (AKD, MS); Writing - review & editing (AKD, SS). All authors read and approved the paper.

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Growth Performance of Mahogany (*Swietenia macrophylla*) under Different Soil Types in Northern Region of Karnataka

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***Abstract*:** The present study was carried out with an objective of assessing growth performance of mahogany (*Swietenia macrophylla*) grown under different soil types of hilly zone of Karnataka. Mahogany plantations with an age gradation of 1, 2, 3, 4 year grown in black and red soils were selected for the study. Growth parameters such as height and girth at breast height were recorded at 12 months interval for a period of one year from January 2022. Growth attributes such as height, girth at breast height, basal area and volume of mahogany at initial stage and at 12 MASE (month after start of experiment) of mahogany differed significantly due to soil type and age gradation. Volume per hectare at initial stage and at 12 MASE was significantly higher in black soil than in red soil. Significantly higher tree volume was recorded in 4-year-old mahogany plantation at initial stage (18.25 m^3) and at 12 MASE (40.55 m^3). Interaction between soil type and age gradation had significant influence on volume per hectare at initial and 12 MASE. The study concluded that growth performance of mahogany was superior in black soil in northern region of Karnataka.

***Keywords*:** Growth performance, Soil types, Fast growing species, Mahogany, *Swietenia macrophylla*

Swietenia macrophylla is a straight grained, reddish brown tropical hardwood species of the family Meliaceae. It is distributed naturally in central and south America. The species has been widely cultivated in south East Asia and the Pacific including India, Indonesia, Philippines and Sri Lanka. It is commonly known as mahogany. With *Swietenia macrophylla*, the species *Swietenia mahagoni* and *Swietenia humilis* are known to be genuine mahoganies. Mahogany was introduced to Royal Botanical Garden, Kolkata from West Indies in 1795. Thereafter this species has been extensively grown in southern India (Akhilraj and Inamati 2023). Mahogany grows normally taller than 30 m and attains a diameter of 150 cm at breast height. It grows in a wide range of soils and environmental conditions. Normally, mahogany requires deep, fertile, well-drained soils with a pH of 6.5-7.5 for its optimum growth and it requires a mean annual rainfall between 1000 and 2500 mm with a 4-month dry period for good growth. Mahogany can grow at an altitude of 0-1500 m above sea level, in areas with a mean annual temperature of 20-28°C (Krisnawati et al 2011). Mahogany is a light demander, frost tender, fire hardy species. It avoids water logging and moderately coppice. The mahogany wood is used for manufacturing doors, windows, composite wood, boat, sports goods and musical instruments. Fruit is known as sky fruit and which is having medicinal properties such as it is used to treat blood sugar, cholesterol and Alzheimer's disease (Akhilraj 2023).

In recent times, incorporation of fast-growing tree species into the agroforestry systems has received more attention among farmers in India due to its diversified outputs and sustained agricultural productivity. Among such fast-growing tree species, mahogany is a promising important tree species considered by the farmers. Its deep rooting nature, moderate fast growth, adoptability, outstanding wood qualities, better form and higher sawn out turn and ability to withstand the stand management practices makes it popular among the tree farmers (Vikas Kumar 2016). The wood production potential is restricted to about 0.7 m^3 ha^{-1} $year^{-1}$ in the country as compared to the world average of 2.1 m^3 ha^{-1} $year^{-1}$, this results in a huge gap between demand and supply of timber (Bijalwan and Dobriyal 2015). Agroforestry plantations including fast growing tree species is an attractive option because they reduce land competition for biomass and food production while providing tree benefits (Chavan et al 2015). Fast growing species are considered as those capable of a mean annual increment of at least 10 cubic meters per hectare under favourable site conditions (FAO 1965). Fast growth of tree is influenced by edaphic, climatic, topographic and biotic factors. Farmers of north Karnataka have started cultivating mahogany extensively in their farm land without prior knowledge on site specificity. Knowledge on suitability of the species to particular soil is crucial in raising the plantation successfully hence present

investigation was carried out with an objective of assessing the growth performance of mahogany under different soil types of northern region of Karnataka.

MATERIAL AND METHODS

The present study was conducted in Hilly zone (11º 56' to 15º 46' N latitude and 74º 31' to 76º 45' E longitude), one among the 10 agroclimatic zones present in Karnataka. It is characterized by red clay loamy soil, lateritic soil and black soil. This zone has a tropical climate with an annual rainfall of 2500-3000 mm. There were two factors considered for the study, factor one was soil type viz. black soil and red soil and factor two was age gradation viz. 1, 2, 3, 4 year. Different aged mahogany plantations grown in black soil and red soils were selected from this agroclimatic zone based on similar growing conditions with utmost care. In each plantation three sample plot of 15 m × 15 m was laid out for measuring the growth parameters. In each sample plot, there were 25 trees with a spacing of 3 × 3 m. The study was conducted in the year 2022 and observations were taken twice ie. at initial stage and at 12 MASE and average data per hectare was calculated. Growth parameters such as tree height (m), girth at breast height (cm) were recorded and derived parameters such as basal area, total tree volume, current annual increment and mean annual increment (Chaturvedi and Khanna 1984) were calculated.

Basal area = $g^2/4\pi$, where g is girth at breast height

Total volume = Tree height × basal area × form factor

The replicated data were statistically were compared using post-hoc test (Duncan's multiple range test) at ($p < 0.05$) level using OPSTAT software.

RESULTS AND DISCUSSION

Growth attributes such as height and girth at breast height significantly differed due to soil type and age gradation. Tree height at initial was significantly higher in black soil (3.71 m) than red soil (3.54 m). Tree height at initial was significantly higher in 4-year plantation (4.93 m) than in 1-3 year similarly tree height at 12 MASE was significantly higher in black soil (4.83 m) than red soil (4.56 m) and significantly higher in 4-year plantation (5.70 m) than 1-3 year of plantation (Table 1). Height growth is directly related to the site quality. Good height growth may be due to the higher potential of black soil in terms of water holding and nutrient status in comparison with red soil. Vasudev et al (2020) indicated similar trend where *Melia dubia* grown in black soil recorded maximum height at initial and at the end of 12 months as compared to red soil. Generally, as tree age increases, the growth in trees also increases. In the present study, mean tree height of mahogany increases as the stand age increases. Similar kind of results were reported by Divya et al (2022) in eucalyptus and Patel et al (2022) in *Ailanthus excelsa*. GBH at initial was significantly higher in black soil (16.53 cm) than red soil (15.87 cm) similarly GBH at 12 MASE was significantly higher in black soil (26.16 cm) than red soil (25.02 cm). Reis et al (2018) reported that soil type and plant age both influenced the increment in diameter at breast height of *Swietenia macrophylla*. Trees from the red yellow acrisol had recorded statistically higher diameter at breast height values than trees from the nitisol (40.05 and 33.57 cm, respectively). GBH at initial was significantly higher in 4-year plantation (24.82 cm) than 1–3-year plantation. GBH at 12 MASE was significantly higher in 4-year plantation (Table 2). Vasudev et al (2020) reported that *Melia dubia* exhibited a higher diameter at beast height in black soil in comparison with red soil.

Volume per hectare at initial stage and at 12 MASE of mahogany differed substantially due to soil type and age gradation (Table 3). Volume per hectare at initial stage was significantly higher in black soil (8.62 m^3) than red soil (7.72 m^3). Volume per hectare at initial stage was significantly higher in 4-year plantation (18.25 m^3). Interaction between soil type and age gradation had significant effect on volume per hectare at initial stage. This was significantly higher in black soil than red soil. Volume per hectare at 12 MASE was significantly higher in black soil (23.26 m^3) than red soil (20.34 m^3) and volume per hectare at 12 MASE was significantly

Table 1. Mean height of mahogany at initial and at 12 MASE as influenced by soil type and age gradation

Soil types / Plantation age	Height (m) at initial stage					Height (m) at 12 MASE				
	1	2	3	4	Mean	1	2	3	4	Mean
Black soil	1.94	3.66	4.22	5.03	3.71	3.62	4.76	5.12	5.83	4.83
Red soil	1.86	3.41	4.06	4.83	3.54	3.36	4.51	4.80	5.56	4.56
Mean	1.90	3.53	4.14	4.93		3.49	4.64	4.96	5.70	
CD (p=0.05)										
Soil type (S)				0.04					0.02	
Plantation age (P)				0.06					0.03	
Interaction (S × P)				0.08					NS	

higher in 4-year-old plantation (40.55 m^3). Interaction between soil type and age gradation had significant influence on volume per hectare at 12 MASE. The higher tree volume obtained in plantation raised in black soil may be due to the fertility and water holding capacity of it. In addition to it mahogany prefers neutral to alkaline soil, black soil provides optimum conditions for the growth than red soil. Vasudev et al (2020) in *Melia dubia* grown in black soil recorded maximum volume as compared to red soil. Current annual increment (CAI) of volume per hectare of mahogany differed considerably due to soil type and age gradation (Fig. 1). Increasing trend of CAI indicate that mahogany grows faster in its early growing stage. Higher CAI and MAI is obtained in plantation grown on black soil compared to red soil. Interaction between soil type and age gradation had significant influence on CAI of volume per hectare. Whereas

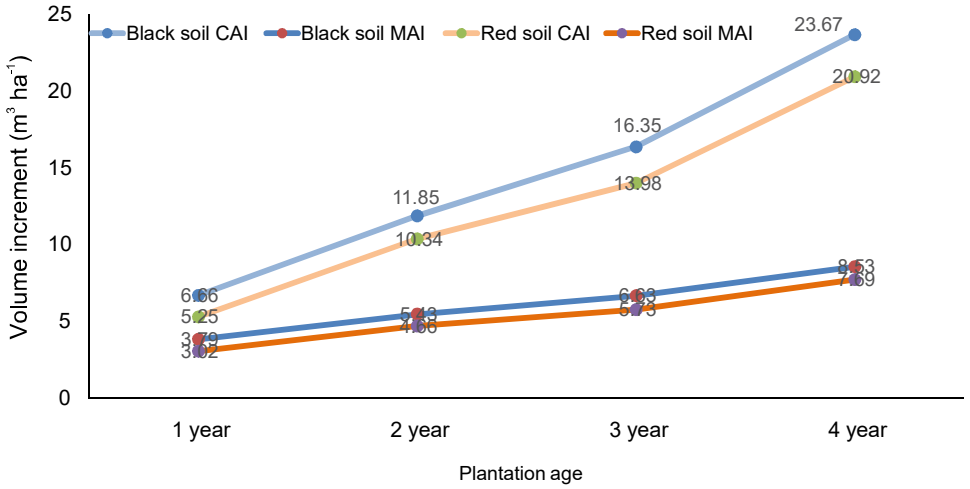

Fig. 1. CAI and MAI of volume (m^3 ha^{-1}) of mahogany as influenced by soil type and age gradation

Table 2. Mean gbh of mahogany at initial stage and at 12 MASE as influenced by soil type and age gradation

Soil types / Plantation age	GBH (cm) at initial stage					GBH (cm) at 12 MASE				
	1	2	3	4	Mean	1	2	3	4	Mean
Black soil	8.17	13.45	19.46	25.05	16.53	17.65	23.18	28.94	34.87	26.16
Red soil	7.72	12.58	18.58	24.58	15.87	16.34	22.06	27.76	33.92	25.02
Mean	7.95	13.02	19.02	24.82		17.00	22.62	28.35	34.40	
CD (p=0.05)										
Soil type (S)				0.28					0.23	
Plantation age (P)				0.40					0.32	
Interaction (S × P)				NS					NS	

Table 3. Total tree volume of mahogany at initial stage and at 12 MASE as influenced by soil type and age gradation

Soil types / Plantation age	Volume (m^3 ha^{-1}) at initial stage					Volume (m^3 ha^{-1}) at 12 MASE				
	1	2	3	4	Mean	1	2	3	4	Mean
Black soil	0.91	4.45	10.17	18.97	8.62	7.58	16.29	26.53	42.63	23.26
Red soil	0.78	3.64	8.92	17.54	7.72	6.03	13.98	22.90	38.46	20.34
Mean	0.85	4.04	9.55	18.25		6.80	15.14	24.72	40.55	
CD (p=0.05)										
Soil type (S)				0.31					0.37	
Plantation age (P)				0.44					0.52	
Interaction (S × P)				0.62					0.74	

interaction between agroclimatic zone and age gradation had no significant influence on MAI of volume per hectare at 12 MASE.

CONCLUSION

Swietenia macrophylla grown in black soil recorded a higher mean tree height, mean girth at breast height and total tree volume per hectare. Hence study concluded that growth performance of mahogany was superior in black soil as compared to red soil in hilly zone of northern region of Karnataka. The current annual increment as well as mean annual increment values were also higher in the case of black soil. Thus, black soil supports the growth of mahogany species in northern region of Karnataka.

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Productivity of Bamboo under Different Felling Intensities in Northern Transitional Zone, Karnataka

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***Abstract*:** Bamboo is an extremely versatile plant capable of providing ecological, economic and livelihood security to the people. Less work has systematically been done on productivity of bamboos based on different felling intensities. Four different species of bamboo (*Bambusa balcooa*, *Dendrocalamus stocksii*, *Dendrocalamus asper, Bambusa vulgaris*) were present in the main agricultural research station, Dharwad. Felling is done based on the selection of culms of three-year-old and above by the Horse-shoe felling method, out of the total culms available within the clump. Four intensity felling's planned to carried out (0, 10, 20 and 30 per cent). The felling intensity of 20 per cent resulted in a greater proliferation of shoots across all four bamboo species when compared to the remaining treatments. Among the recorded instances of shoot emergence, the utmost count of shoots emerged was 9, specifically within *B. balcooa* subject to a felling intensity of 20 per cent. The new shoots of both *D. stocksii* and *B. balcooa* emerged not solely along the peripheries of the clumps, but also within the clumps themselves. The emergence of new culms primarily occurs at the onset of the monsoon and varies based on bamboo species, harvesting techniques, climate conditions etc.

***Keywords*:** Bamboo species, Culm emergence, Felling intensities, Productivity

Agroforestry with bamboos has the potential to dramatically improve output, sustainability, and resource protection (Dev et al 2016). Many thorn less bamboo species are appropriate for agroforestry and can survive alongside trees, herbs, and crops in the same ecological area. Bamboos offer several advantages over trees, including rapid growth rate, short rotation, wide adaptability, low maintenance practises, diverse uses, carbon sequestration potential, soil and water conservation. Bamboo is an exceptionally adaptable plant that can provide people with ecological, economic, and livelihood security. Bamboo reaches structural maturity in three years, and the mean annual increment of medium or large sized bamboos is comparable to or greater than that of several other rapidly growing tree species (Banerjee et al 2009). Bamboo thrives in a variety of habitats, including tropical, subtropical, and temperate regions with annual rainfall ranging from 1,200 to 4,000 mm with temperature changes ranging from 16°C to 38°C. Less work has systematically been done so far on productivity of bamboos based on different felling intensities. The implementation of various bamboo culm felling intensities contributes significantly to augmenting the emergence of new bamboo shoots. This phenomenon, in turn, exerts a favourable influence on the production of bamboo shoots. As a result, the proposed bamboo treatments, particularly those incorporating intensive felling processes, hold substantial potential to assist silviculturists, departmental personnel, and managers engaged in bamboo cultivation aimed at future shoot production. Moreover, the stimulation of new shoot growth through felling intensity treatments can effectively enhance the economic prospects of entrepreneurs and farmers, particularly in the context of large-scale bamboo plantations focused on shoot production. This correlation between bamboo species productivity and the emergence of new shoots underscores the significance of the objective of study.

MATERIAL AND METHODS

The investigation of the present study on productivity of bamboo under different felling intensities in Northern Transitional Zone, Karnataka was conducted in an existing Bamboo plantation (Established in November 20, 2017) at UAS, Dharwad, Karnataka during 2021-2022. Four different species of bamboo (*Bambusa balcooa*, *Dendrocalamus stocksii*, *Dendrocalamus asper, Bambusa vulgaris*) were present in the field. 6m x 3m was the spacing adopted between bamboo clumps. The experiment was laid out in two factor Randomized complete block design where, different bamboo species (T) and different intensity felling's (F.I) are treated as two factors with six replications. Felling is done based on the selection of culms of three-year-old and above by the Horse-shoe felling method, out of the total culms available within the clump. New culms are generally formed along the clump's periphery and immature culms (< 3 years

old) are not strong and durable, hence they have limited demand and are particularly susceptible to pests and illnesses. As a result, aged or matured culms (> 3 years old) are harvested whereas less than 3-year-old culms are left in the clump. In horse shoe felling method, a 50-90 cm wide path has to be created inside the clump so that one can enter into the middle part of the clump to start harvesting and dragging out the culms which are three years old and above. Four intensity felling's planned to carried out (0, 10, 20 and 30 per cent). A felling intensity of twenty per cent means 20 per cent of the total mature culms in each clump in the assigned plot were felled. New shoots was observed to determine the frequency of the shoots emerged. The distribution pattern of the shoots emerging within the clump area is also observed.

RESULTS AND DISCUSSION

There was a substantial variance in the number of shoots that emerged across the various treatments. The felling intensity of 20 per cent resulted in a greater proliferation of shoots across all four bamboo species when compared to the control, as well as felling intensities of 10 per cent and 30 per cent (Table 1). Among the recorded instances of shoot sprouting, the utmost count of shoots emerged was 9, specifically within *Bambusa balcooa* subject to a felling intensity of 20 per cent. Conversely, the remaining felling intensities viz., the control, 10 per cent and 30 per cent exhibited comparable results. In the case of *Dendrocalamus stocksii*, a felling intensity of 20 per cent yielded a significantly higher count of shoots (4.00), followed closely by a felling intensity of 10 per cent, which was statistically equivalent to the control (2.67). *Dendrocalamus asper* displayed elevated count of shoots (8.33) at a felling intensity of 20 per cent, whereas the other thinning percentages (0 per cent, 10 per cent, and 30 per cent) demonstrated parallel outcomes. Among interactions, *B. balcooa* with 20 per cent intensity felling resulted in statistically higher culm emergence (9.33 culms). Mohamed et al (2007) observed that 30 per cent felling intensity exhibited a favourable impact on shoot emergence throughout the study period. Nevertheless, 60 per cent felling intensity was comparable to the control. After the initial felling at the planned intensities of 0, 30, and 60 per cent, new shoots of *Gigantochloa ligulata* emerged along clump peripheries and within the clumps.

Among all the examined species, *Bambusa balcooa* (9.33) and *D. asper* (8.33) exhibited higher number of newly sprouted shoots. Newly emerged shoots were higher at a felling intensity of 20 per cent for *Bambusa vulgaris*, surpassing other felling intensities. Among all four felling intensities, *B. balcooa* exhibited significantly greater newly sprouted shoots. The emergence of new culms primarily occurs at the onset of the monsoon season, typically in May or June, and extends over 4 to 5 months until October or November. Shoots sprouting at the start of the growing season (March-April) are limited. Subsequently, a rapid increase is observed during June to July, followed by a gradual decline in the subsequent months. It's advised not to harvest culms from bamboo clumps during the culm sprouting period (May to November).

The number of new culms arising from a bamboo clump varies based on bamboo species, harvesting techniques, soil and climate conditions, clump size, overhead coverage, etc. The timing and distribution of monsoon rains significantly impact new culm emergence; timely and even rainfall fosters positive outcomes, while untimely rains or breaks after showers hinder culm emergence. The availability of reserve nutrients also plays a pivotal role in influencing bamboo culm and rhizome emergence. The highest reserve starch levels in one-year-old culms are just before sprouting, decreasing during sprout growth and then increasing after growth completion. The Figures 1 to 4 depict the original clumps,

Table 1. Influence of different felling intensities on new bamboo shoot emergence in different thorn less bamboo species

Treatment	New shoot emergence as influenced by different felling intensities				
	0% (Control)	10%	20%	30%	Mean
Bambusa balcooa (T1)	5.67	6.00	9.33	6.00	6.75
Dendrocalamus stocksii (T2)	2.67	3.33	4.00	2.33	3.08
Dendrocalamus asper (T3)	6.00	6.00	8.33	6.00	6.58
Bambusa vulgaris (T4)	2.67	3.00	4.33	3.00	3.25
Mean	4.25	4.58	6.50	4.33	
For comparing the means of				CD (p=0.05)	
Treatments (T)				0.50	
Felling intensity (F.I)				0.50	
Interaction (T X F.I)				0.99	

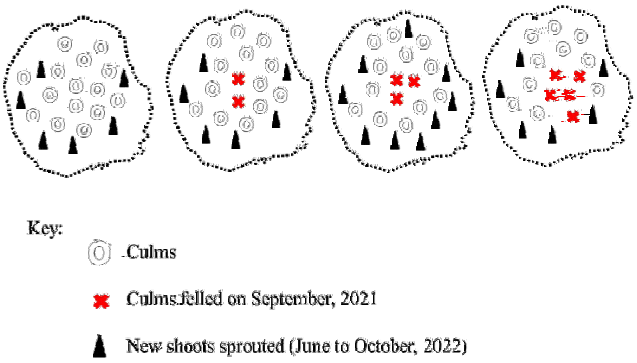

Fig. 1. Dispersion map of *Bambusa balcooa* showing pattern of new shoot recruitments under different felling intensities

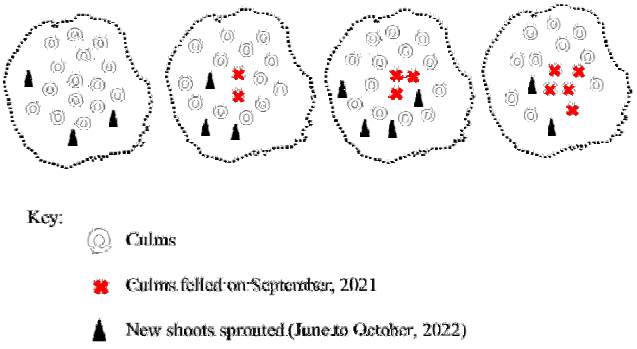

Fig. 2. Dispersion map of *D. stocksii* showing pattern of new shoot recruitments under different felling intensities

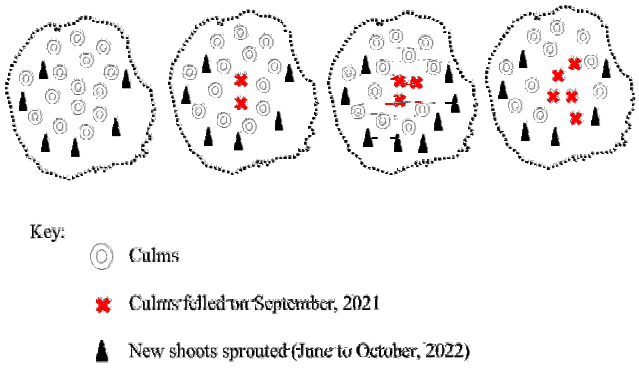

Fig. 3. Dispersion map of *D. asper* showing pattern of new shoot recruitments under different felling intensities

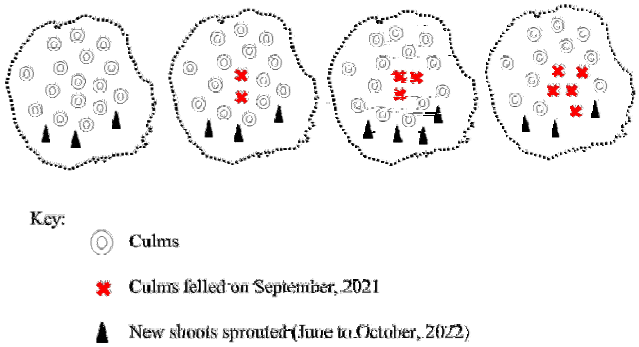

Fig. 4. Dispersion map of *B. vulgaris* showing pattern of new shoot recruitments under different felling intensities

illustrating the distribution of all initial available culms prior to felling. These figures also showcase the quantities of culms felled corresponding to different felling intensities, along with the subsequent emergence of new shoots in the following year. The new shoots of both *Dendrocalamus stocksii* and *Bambusa balcooa* emerged not solely along the peripheries of the clumps, but also within the clumps themselves. Conversely, the remaining two bamboo clumps displayed newly emerged shoots exclusively along their peripheries.

CONCLUSION

The highest count of newly sprouted culms was observed at a felling intensity of 20 per cent. The other three felling intensities, viz., 0 per cent (control), 10 per cent and 30 per cent, exhibited on par values for all the species of bamboo. In case of *Dendrocalamus stocksii* and *B. balcooa*, the newly sprouted culms appeared not only around the periphery of the clumps but also within them. However, for the other two bamboo species, newly emerged culms were exclusively present along the periphery of the clumps.

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Studies on Integrated Nutrient Management in Black Pepper under Agroforestry System

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***Abstract*:** Black pepper (*Piper nigrum* L.) is one of the oldest and most expensive spices ever known to mankind.. An experiment was conducted in 2022-23 with the objective of studying the effect of integrated nutrient management on the yield and quality parameters of black pepper under agroforestry system. The application of 75% RDF + *Azospirillum* (50 g) +PSB (50 g) +VAM (100g) per vine reported a greater performance on yield and yield attributing parameters. The number of spikes ranged from 36 to 103 and their lengths from 4.9 to 14.5. The number of berries per spike and dry yield of black pepper per vine ranged from 26 to 81 and 76.6 to 403 grams. The minimum values for the studied parameters were in the control. Black pepper quality parameters viz., oleoresin and piperine content were not affected by different nutrient management practices except for the control. The present study indicated that yield parameters differed significantly with different nutrient management practices.

***Keywords*:** Black pepper, Piperine, Oleoresin, Agroforestry system, *Piper nigrum* L.

Agroforestry is an age-old practice in India which combines woody perennials along with crops and /or animals on the same unit of land management. Black pepper *(Piper nigrum* L.*)* is one of the oldest and most expensive spice ever known to mankind. It is prized for its aroma, which results from the presence of essential oil within the berries, and for its pungency, which results from the principal alkaloid piperine. Black pepper is cultivated for its fruits, which are typically dried and used as spice. It is chiefly used in traditional medicines and for culinary uses (Ravindran et al 2000) and is traditionally cultivated under a few support trees like coconut and areca nuts (conventional species). Numerous MPTs (multipurpose tree species) are also appropriate for pepper block growing. Silver oak (*Grevillea robusta*) is a member of the Proteaceae family. It is indigenous to Australia's east coast but is also widely distributed in India. Silver Oak tree provides timber, is used to make cricket bat, acts as a windbreak, provides shade for plantations and serves as a stake for climbers like pepper (Umashankar et al 2012). Coffee is one of the plantation crop cultivated and produced in India that contributes significantly in foreign money to the country's revenue. The two most prevalent species of coffee grown and consumed worldwide are Arabica coffee (*Coffea arabica*) and Robusta coffee (*Coffea canephora*). Recent trends shows that intense usage of fertilizers without considering adequate soil management practices contributes to global decline in soil productivity and fertility (Pannaga et al 2021). The forestry enterprise is increasingly utilizing the recently developed method of integrated nutrient management and improves productivity and soil properties, which benefits plant performance. Sustainable crop production is facilitated by an integrated approach to nutrient management, which improves soil organic matter and easily available plant nutrients. Organic manures and bio fertilisers can replace between 25 per cent and 50 per cent of chemical fertilisers now used (Kandeel et al 2002). Black pepper is a highly nutrient exhausting crop so the crop nutritional requirement should be considered seriously. The present investigation was carried out to study the influence of integrated nutrient management on the yield, yield attributing and quality parameters of black pepper under silver oak - black pepper-coffee based agroforestry system.

MATERIAL AND METHODS

The present study was carried out in Uttar Kannada district, Karnataka, where two year old black pepper vines were trailed on three year old silver oak trees. Silver oak trees were planted at a spacing of 3 m × 3m. In between two silver oak trees, two coffee plants were planted at a spacing of 1.2 m × 1.2 m between the coffee plants and 0.9 m × 0.9 m between the coffee plant and the silver oak tree. Coffee plants were two year old. The variety of coffee plant was *Coffea arabica,* while the variety of black pepper used was panniyur 2. The experiment was laid out in randomized block design with nine treatments and three replications. The treatments were applied for eight vines per replication. The various treatments adopted were:

$T_{1.}$ RDF (100:40:140g)

T_2- 50% RDF + (Azospirillum 50g +PSB 50g +VAM 100 g)
T_3- 75% RDF + (Azospirillum 50 g +PSB 50 g +VAM 100g)
T_4- 50% RDF + 50 % N in the form of vermicompost
T_5-50% RDF+ 50 % N in the form of FYM
T_6-75% RDF+ 25 % N in the form of vermicompost
T_7-75 % RDF+ 25 % N in the form of FYM
T_8-Farmer practice (10 kg FYM +5 kg Forest Litter)
T_9-Control

For every treatment except for control and farmers practice, additional 10 kg FYM per vine was applied. The details on RDF was collected from package of practice published by University of Horticultural Sciences, Bagalkot. The nutrients were applied in two split doses. In July first week of 2022, the first split was applied by creating ring basins surrounding each vine. The second split was applied in the month of November 2022. All the matured black pepper spikes from each replications were harvested towards the end of January 2023. Chemical fertilizers containing nitrogen, phosphorus, and potassium were applied in the form of urea (N), rock phosphate (P) and muriate of potash (K) according to the treatment instructions. Bio-fertilizers such as vesicular arbuscular mycorrhiza (VAM), phosphorus solubilizing bacteria (PSB) and *Azospirillum* culture were inoculated to FYM and applied to the black pepper vines according to the treatments. The forest litter application was in the form of leaf prunings (Silver oak). The various yield, yield attributing and quality parameters *viz.,* yield (g/vine), no of spikes per column, length of the spike (cm), no of berries per spike, fresh weight of spikes per vine (g/vine), piperine and oleoresin content were estimated and the averages were worked out. The harvested spikes were threshed, dried in open sun and dry weight was taken as yield per vine. The piperine content was estimated by UV spectrophotometer (Anonymous, 2005) while the oleoresin content was estimated by soxhlet apparatus (Ravindran et al 2000).

RESULTS AND DISCUSSION

The combined application of organic, inorganic, and bio-fertilizers had a significant impact on the yield and yield attributing parameters after seven months of experiment except for the test weight of 100 dried berries (Table 1). Among the treatments, T_3 [75 % RDF + *Azospirillum* (50 g) + PSB (50 g) + VAM (100 g)] recorded the highest, while T_9 (control) recorded least values for all the studied parameters. The test weight of 100 dried berries was non-significant for all treatments. High values for yield and yield attributes in black pepper *viz.,* number of spikes per vine (103.66), spike length (14.53 cm), number of berries per spike (81.66), fresh weight of spikes per vine (1443.33 g/vine) and dry yield (403 g/vine) may be attributed to quick supply of nutrients in the form of NPK. The vesicular arbuscular mycorrhiza might have improved the availability and absorption of all important nutrients which enabled more phosphorus uptake and accumulation in leaf tissues and enhanced the photosynthetic process, glucose translocation and accumulation. The dry yield was maximum for T_3(403 g/vine). Arya et al (2013) also revealed that a greater number of berries are produced from longer spikes and hence increases the yield. Vargese et al (2021) observed that the application of 100 % RDF +*Azospirillum* + PSB + VAM gave higher performance in terms of yield (2.5 kg/vine) and yield attributing factors. Non-significant result observed in test weight of 100 dried berries (5.02 g) of black pepper may be attributed to genotypic character of the cultivar used. The

Table 1. Yield, yield attributes and quality parameters of black pepper as influenced by different integrated nutrient management practices

Treatment	No. of spikes per vine	Spike length (cm)	No of berries per spike	Test wt. of 100 dried berries (g)	Fresh yield of spikes per vine (g/vine)	Dry yield (g/vine)	Oleoresin (%)	Piperine (%)
T_1	91.33	12.13	69.00	5.02	1233.33	351.66	7.37	2.34
T_2	93.66	12.50	71.33	5.02	1253.33	357.66	7.37	2.36
T_3	103.66	14.53	81.66	5.02	1443.33	403.00	7.38	2.32
T_4	86.33	10.16	62.33	5.02	857.00	269.33	7.36	2.34
T_5	74.00	7.80	47.66	5.02	767.66	192.00	7.37	2.35
T_6	84	9.93	55.66	5.02	853.00	262.33	7.36	2.35
T_7	76.66	8.80	48.00	5.02	768.70	226.66	7.35	2.35
T_8	47.33	7.50	40.00	5.02	399.00	172.66	7.37	2.33
T_9	36.66	4.93	26.33	5.02	287.00	76.66	6.83	2.13
Mean	77.07	9.80	55.77	5.02	873.47	256.88	7.30	2.31
CD (p=0.05)	2.49	0.41	5.09	NS	20.15	8.65	0.07	0.041

highest spike length was reported in T_3 (14.53). The enhancement of spike length could be possibly due to internodal elongation and cell expansion and growth The number of berries per spike was observed maximum in T_3 (81.66). This was mainly due to the longer spike length of T_3 spikes (14.53 cm).This was in line with Tripathi et al (2018).The fresh weight of spikes was maximum for T_3 (1443.33 g/vine) might be because of starch content, boldness and stage of harvest of the spikes. Sruthi et al (2013) also observed same trend. Statistically non-significant results were for piperine and oleoresin content under various nutrient combinations. The T_3 (7.38 %) and T_2 (2.36 %) recorded maximum oleoresin and piperine content respectively. Subramanian et al (2016) confirmed that black pepper quality parameters such as oleoresin and piperine content were not affected by different integrated nutrient management practices.

CONCLUSION

The study on integrated nutrient management in black pepper under silver oak-black pepper-coffee based agroforestry system indicates that integrated application of organic, inorganic and biofertilizers are good for yield of black pepper. The application of 75 % NPK + *Azospirillum* (50 g) +PSB (50 g) +VAM (100g) per vine are recommended for higher yield in black pepper.

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Adoption of Natural Farming Practices and Perception of Farmers towards its Economic and Ecological Impacts

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***Abstract*:** Natural farming is a climate resilient farming system that enhances soil conditions, reduces water requirements, enhances biomass recycling, biodiversity and biological interactions. The study evaluated the extent of adoption and farmers' perception of the ecological impacts of natural farming on the basis of primary data collected from 120 farmers. The majority of farmers have observed that intercropping to be more advantageous than mono-cropping along with improvement in soil health, declined pest attacks and cost of cultivation. Farmers were also convinced about the impact of natural farming on mitigating climate change and health benefits of natural farm products. The study has concluded that natural farming promotion efforts must be sustained further to strengthen its adoption process and to change farmers' perception of natural farming by educating them about the environmental and economic benefits of natural farming.

Keywords: Natural farming, Adoption, Perception, Environment, Health & Intercropping

In India, the agriculture sector is very important as it is indispensable for the sustenance and growth of the Indian economy. More than half of the population relies directly or indirectly on agriculture (Chand and Singh 2022). Nowadays, the green revolution's exuberance is disappearing and it is becoming clear that the entire technology has left a negative impact on the environment. Extensive use of chemicals has led to many health and environmental issues (Iqbal et al 2001, Kotschi 2015). Due to a number of factors, modern chemical-based agriculture has increased production costs or decreased crop yield. (Ayansina and Oso 2006, Sreenivasa et al 2010, Singh et al 2011). The biological function of the soil was seriously harmed. Over 1 billion people in developing countries already have their livelihoods, financial security and nutritional health in danger as a result of land degradation (FAO 2016). Sustainability in agricultural production has emerged as one of the most significant concerns of the present and the need was felt to introduce a farming system that can ensure enhanced farm income and reduces dependence on external inputs. There is an increased emphasis on promoting such farming practices that provide ecosystem services and greater economic benefits on a sustainable basis. The introduction of natural farming is a viable and sustainable option to achieve the objectives mentioned above (Palekar 2006). Natural Farming is being implemented by the Government of Himachal Pradesh as the 'Prakritik Kheti Khushhal Kisan Yojana' (PK3Y) since 2018 and is based on a holistic system built upon principles of Natural Farming. This system improves ecology by enhancing soil health through bio-inoculation, continuous vegetation cover on the farms, and reduced tillage resulting in increased sequestration of carbon in soils. The purpose of this study is to highlight the adoption level of various natural farming practices, spotlight the perceptions of farmers regarding various ecological and economic benefits of natural farming practices on fields, and suggest actions that might reduce chemical input use on farms.

MATERIAL AND METHODS

Kangra and Solan districts of Himachal Pradesh were purposively selected for the present study. Multiple stage random sampling design was adopted to select the natural farming practicing farmers. In the first stage two blocks from each district namely Kangra and Indora blocks from district Kangra and Solan and Kandaghat blocks from district Solan were randomly selected. Six villages were randomly selected from each block, where natural farming was being practiced by the farmers. In the next stage, a list of farmers practicing natural farming was procured from concerned officials and five farmers from each village were selected randomly. Thus a sample of 120 farmers was selected for the study and they were further categorized into two categories *viz* small (having holding size less than 1 ha) and large (having holding size more than or equal to 1 ha) (Table 1).

Nature and source of data: Primary data were collected to

meet the objectives of the present study from the farmers practicing natural farming by personal interview method using a well-structured and pretested schedule. The tabular techniques, percentages and suitable analytical tools like Adoption Index and Chi-square test have been employed for the analysis of the data.

Adoption index: The extent of adoption was calculated by selecting application of indigenous agricultural practices i.e. *Beejamrit*, *Jeevamrit Ghanjeevamrit, Neemastra/ Agnistra/ Brahmastra*, *Khatti* lassi, mixed cropping, *Achhadana*/ green mulching and *Wapasa*. Adoption index was measured on three-point continuum as full adoption, partial adoption and non-adoption by assigning the score of 2, 1 and 0, respectively. The scores obtained for all the practices were summed up for each respondent and the adoption score was calculated by applying following formula (Wadekar et al 2017);

$$\text{Adoption Index} = \frac{\text{Obtained Adoption score}}{\text{Maximum obtainable adoption score}}$$

According to adoption index, respondents were categorized into three categories i.e. poorly adopted (0-0.25), partially adopted (0.25-0.75) and highly adopted (0.75-1).

Chi-square test: To test whether there was any significant difference among small and large farms of study area for the perception about natural farming. Chi-square test in (m x n) contingency table was applied where m and n are perception of farmers for different factors the farm categories. The detail of approximate Chi-square test is given as under:

$$\sum_{j=1}^{l}\sum_{i=1}^{K}\frac{(O-E)^2}{E}X^2\,(\mathrm{L}-1)(\mathrm{K}-1)\mathrm{d.f}$$

where, O = Observed values, E = Expected values, K = Number of problems, L = Number of farm size groups.

Table 1. Distribution of sampled households according to their land holdings

Category of farmers	No. of farmers	Average size of landholding (ha)
Small (<1 ha)	86 (71.67)	0.44
Large (>1ha)	34 (28.33)	1.84
Total	120 (100)	0.84

RESULTS AND DISCUSSION

Adoption pattern: In order to study the adoption pattern and extent of adoption, adoption index was calculated in which eight components of natural farming were selected (Table 2). There was a gap in the adoption of natural farming. Therefore, farmers were categorized in three categories fully adopted, partially adopted and no adoption category on the basis of their adoption pattern. A few questions were asked from farmers like for *Beejamrit*, they were asked whether they had treated the seeds with it or not? And for *Jeevamrit*, whether it was sprayed after 21 days or not? Similar questions were asked for *Ghanjeevamrit*. For plant protection solutions, farmers were categorized on the basis of time of application i.e., before or after emergence of insect/pest. In case of *Achhadana*/green mulching and *Wapasa*, farmers were categorized on the basis of direct observation on their farm. From the table it can be observed that 91.67 per cent of farmers have treated the seeds with *Beejamrit,* 45 per cent of farmers have made channels for *Wapasa* and 70 per cent of farmers were using *Khatti lassi* as fungicide. 60.83 per cent of farmers have fully adopted the application practices of *Jeevamrit*. However, in case *Ghanjeevamrit* (46.67 & 53.33%) and plant protection solution (41.67 & 58.33%) the farmers completely following natural farming practices were found at par with those

Table 2. Percentage of the farmers using different components of SPNF in the study area

(Per cent)

Particulars	Full adopted	Partial adopted	No adoption
Beejamrit	91.67	-	8.33
Jeevamrit	60.83	39.17	-
Ghanjeevamrit	46.67	53.33	-
Neemastra/Agnistra/Brahmastra	41.67	58.33	-
Khatti Lassi	70.00	30.00	-
Mixed cropping	76.67	14.17	9.17
Achhadana/Green mulching	53.33	25.00	21.67
Wapasa	45.00	15.00	40.00
Total number of farmers	120	120	120

following it partially. In case of mixed cropping, only 76.67 per cent of farmers were actually following the pattern of intercropping while 9.17 per cent of farmers were still following the mono-cropping under natural farming system.

Adoption index: The majority (65.83 %) of the respondents had medium level of adoption, followed by (34.17 %) high levelof adoption and no respondent was in the category of poorly adopted (Table 3). Overall the adoption index was 0.75, indicating that majority of the farmers have partially adopted the SPNF practices. The medium level of adoption can be attributed to unawareness regarding the complete package of SPNF system coupled with the laborious work needed for its proper implementation.

Table 3. Adoption index

Adoption category	No. of farmers	Adoption index
Poorly adopted	0 0.00	0 to 0.25
Partially Adopted	79 (65.83)	0.25 to 0.75
Highly Adopted	41 (34.17)	0.75 to 1
Overall Adoption Index	120 (100.00)	0.75

Figures in parentheses represent the percent of total

Perception of farmers towards natural farming: Among different factors perception of crop diversification, perceived benefits of intercropping, change in the cost of cultivation, climate change impacts and labour intensive methods were statistically significant (Table 4). There was significant difference between the different farm categories, whereas the rest of the factors were found statistically insignificant which indicated that they were independent to farm categories.

Table 4. Perception of farmers towards natural farming

Factors		Small (n=86)	Large (n=34)	Overall (n=120)	X^2
Crop diversification	Yes	61.63	88.24	69.17	8.089**
	No	38.37	11.76	30.83	
Perceived benefits of intercropping	Agree	62.79	82.35	68.33	5.042*
	Disagree	10.47	8.82	10.00	
	Neutral	26.74	8.82	21.67	
Impact on crop health (Pest attack)	Increased	15.12	8.82	13.33	0.891
	Decreased	67.44	70.59	68.33	
	Neutral	17.44	20.59	18.33	
Impact on land (Soil health increased)	Agree	83.72	79.41	82.50	0.313
	Disagree	6.98	8.82	7.50	
	Neutral	9.30	11.76	10.00	
NF inputs are better than chemical inputs	Agree	79.07	85.29	80.83	1.432
	Disagree	9.30	2.94	7.50	
	Neutral	11.63	11.76	11.67	
Change in cost of cultivation	Increased	8.14	5.88	7.50	70.415***
	Decreased	81.40	79.41	80.83	
	Neutral	10.47	14.71	11.67	
It can mitigate climate change impacts	Agree	73.26	88.24	77.50	8.972**
	Disagree	5.81	11.76	7.50	
	Neutral	20.93	0.00	15.00	
The method is labour intensive	Agree	70.93	91.18	76.67	5.583**
	Disagree	29.07	8.82	23.33	
Provides health benefits to the consumers	Agree	95.35	91.18	94.17	0.772
	Disagree	0.00	0.00	0.00	
	Neutral	4.65	8.82	5.83	
Adoption of SPNF on large scale is possible	Agree	30.23	20.59	27.50	2.467
	Disagree	48.84	64.71	53.33	
	Neutral	20.93	14.71	19.17	

***Significant at 10% level; **Significant at 5% level; *Significant at 1% level

Impact on crop diversification: To assess the impact on crop diversification, farmers were asked if they had started growing additional crops/plants since the adoption of SPNF. 69.17 per cent of farmers have started growing additional crop on their land since the adoption of SPNF and farm category wise it was observed as 88.24 per cent on large farm and 61.63 per cent on small farm category. Chi-square value of 8.089 denoted that the differences between the categories were statistically significant with the land holding which indicated that there was a direct relationship between the land size owned by the farmer and their propensity to adopt crop diversification

Perceived benefits of intercropping: Farmers' perceptions on benefits of intercropping were documented and it was observed that 68.33 per cent of farmers were of the opinion that intercropping was more advantageous than mono-cropping. Chi-square results (5.042) also indicated that the differences between the categories have a high statistical significance. After adopting the SPNF practices, 68.33 per cent of farmers reported that pest attack has decreased while13.33 per cent of the farmers reported an increase and 18.33 per cent of farmers were of the neutral opinion.

Impact on pest incidence: For insect and pest management, ZBNF encourages the use of various *kashayams* (decoctions) made with cow dung, cow urine, lilac and green chilies. In this context farmers were asked whether they have observed change in the incidence of pest since the adoption of SPNF. The 68.33 % of farmers reported a decline in pest attack, 13.33 % reported an increase, while 18.33 % of farmers were of the neutral opinion. Farm category wise 70.59 % of large and 67.44 % of small farm category were of the opinion that the pest attack has decreased.

Impact on land degradation: The 82.50 % of farmers agreed that the overall health of the soil has increased along with a decrease in soil erosion. The 80 % of farmers across different categories have realized the impact of SPNF in checking the menace of land erosion and have also observed that reduction or no-tillage practices leads to undisturbed soil with lesser chances of soil erosion which also helped them to improve the soil health.

Impact on farmers' perception of natural farm inputs: In the studied area, 80.83 % of farmers found natural farm inputs better than chemical inputs, while 11.67 % remained in ambiguity about the same. The 79.07 % of small farmers and 85.29 % of large farmers had a positive shift towards the preference for natural farm inputs.

Change in cost of cultivation: After adopting natural farming, farmers were using inputs which were available on their farms and was observed that 80.83 % of the farmers reported that the cost of cultivation had decreased, while 7.50 % felt that it has increased and 11.67 % of farmers paused in perplexity. The Chi-square value (70.415) indicated that the differences between the categories are statistically significant which means the cost of cultivation varies significantly from small farm to large farm category.

Climate resilient farming: Farmers' response regarding climate change impact indicated that 77.50 % of farmers agreed that natural farming can mitigate climate change impact, while 7.50 % of farmers disagreed and 15 % of farmers remained in ambiguity about the same. The Chi-square value of 8.972 showed that the differences between the farm categories are statistically significant which indicated that opinion of farmers towards climate change impact varied significantly according to the landholding of the farmers.

Labour intensive practice: The 76.67 % of farmers agreed that natural farming is labour intensive, while 23.33 % of farmers did not find this practice laborious. At farm category wise, 91.18 % of large farmers and 70.93 % of small farmers agreed that natural farming is labour intensive technique. For this factor also, Chi-square value of 5.583 indicated that the differences between the categories are statistically significant with land holding.

Impact on consumer's health: It is well known that natural farming does not require any synthetic chemical inputs on the farm and the perception of farmers in this context have also been recorded. The 94.17 % of farmers have agreed that natural farm products have high health benefits and 5.83 % of farmers were paused in perplexity. It also revealed that none of the farmers were of opinion that natural farm products did have any side effects on health.

Upscaling of natural farming: Most of the farmers (53.33 %) believed that it is not possible to adopt natural farming at large scale due the many factors and one of which may be it being labour intensive. Only 27.50 % of farmers agreed that SPNF can be adopted on large scale. However, 19.17% were of neutral opinion and were not sure about it.

CONCLUSION

Natural farming, a call for the adoption is a paradigmatic shift in crop production practices. Overall adoption index indicated that majority of the farmers have partially adopted the SPNF practices followed by high level of adoption and no respondent was found in the no adoption category. Perception based results indicated that majority of the farmers have started growing additional crop on their land since the adoption of SPNF and they have also reported a decline in pest attack. Almost all the farmers agreed that overall health of soil has increased including decrease in soil

erosion and it was evident from the results that farmers had noticed a sharp decrease in the cost of production. Additionally, majority of the farmers have also agreed that natural farming can mitigate climate change impact. From this study it can be concluded that there is vast scope for coverage of natural farming in the state and the government should undertake policy measures by regular handholding of the SPNF farmers for restoring soil health, protect human health and minimize loss of biodiversity to save the livelihoods of farmers.

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Innovative Post Harvest Management of Residue through Adoption of Super Seeder

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***Abstract*:** During the time of wheat sowing, farmers generally burn paddy residue in north states in India, which decrease the soil fertility and produce harmful gases for human beings, animals and environment. Super Seeder is the most successful implement for sowing wheat in paddy residue without burning straw. A study was planned in Fatehabad district of Haryana state (India) among 120 adopters and non-adopter farmers to judge the level of adoption of super seeder and socio-economic factors associated with the adoption level along with socio-economic impact of adoption of Super Seeder. There was high level of adoption among farmers regarding Super Seeder (53.33 per cent) followed by medium and low level of adoption. Factors significantly associated with adoption level were age, education of the respondents, size of land holding, subsidiary occupation, annual income, social participation, mass media exposure and socio-economic status of the adopter farmers. Overwhelming majority of the medium size land holding farmers (85.71%) reported increase in good lesioning with extension officials and increased expenditure on performance of social ceremonies.

***Keywords*:** Super seeder, Stubble burning, Environment pollution, Wheat, Paddy, Socio economic impact

Rice and wheat are the two main crops grown in North West India, with a cropping intensity of roughly 200 percent. In 15-20 days following paddy harvest, an enormous quantity of straw needs to be managed in order to grow the following wheat crop on the same land. Farmers opt to burn crop remains because they interfere with the processes necessary to grow following wheat crop. About one ton of paddy straw includes 400 kg of carbon, 50-70% of the micronutrients that rice may absorb 1.2 kg of S, 2.3 kg of P2O5, and 5.5 kg of nitrogen (Patel et al 2022). While burning the straw, these micronutrients were lost, which not only results in financial loss but also deteriorates the health of the soil. In the northwest Indian states of Punjab, Haryana, Uttarakhand, and western Uttar Pradesh, rice-wheat cropping system (RWCS) takes up about 4.1 Mha of land and 34 Mt of rice residue produced in these states. (Singh et al 2020).

In Haryana, 80% of the state's i.e. 4.42 million hectares of total land area is used for agriculture, with irrigated land making up 84% of the total area under cultivation. The state produces 13.1 million tonnes of food grains, with a cultivation intensity of 181%. Paddy-wheat crop rotation is one of the most popular in the state. (Rakshit et al 2021). Under this arrangement, farmers benefit more, but they also deplete natural resources like groundwater, soil fertility, soil fauna and flora. In addition, they harmed agro-ecosystem, increased insect pest and disease resistance, decreased soil organic matter, and did other things to the agro-ecosystem. It has been estimated that this crop rotation will result in around 40 million tonnes of crop waste. (Kathpalia et al 2022) Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods in the Indo-Gangetic plains is an important source of atmospheric pollution in this region (Venkataraman et al 2006). The paddy residue burning by farmers lack of sufficient time to sow next crop because require one and half months to decompose and ranked first, followed by paddy straw management delays wheat sowing, paddy residue burning is cheap option , paddy residue (except for Basmati variety) are harder to chew by animals . Farmers are not satisfied with adoption of machines and use of combine harvester machine leaves large straw after harvesting *etc.* (Rohilla et al 2022). To reduce losses from crop residue burning, many straw management techniques have been developed. The special machine called Super Seeder is used to plant seeds in standing stubble crops. The Super Seeder is a single-pass solution that meets the demands of modern farming and prevents crop residue burning. This tractor-operated tool performs three tasks at once: it prepares the land for the subsequent crop by ploughing and simultaneously incorporates crop residue from the previous crop and sows seeds for the subsequent crop. In a single process, all of these tasks are completed along with straw management. The Super Seeder has a zero till drill and rotavator for

handling the paddy straw and wheat sowing, respectively. The rotavator which cut the standing stubbles, loose straw and it will incorporate into the soil. Seed bed preparation also done by passage of rotavator, placement of the seeds takes place in the soil at a time. Super Seeder is an eco-friendly and it also conserves the soil moisture content (Arigela 2023). So keeping in mind the operational benefits of Super Seeder a study was planned to know the adoption of the farmers regarding Super Seeder along with factors associated with adoption level and to find out the socio economic impact of adoption on the farmers' families.

MATERIAL AND METHODS

The study was conducted in Fatehabad, one of the district of Haryana State of India located on the latitude of 29.511778 and the longitude of 75.455215. The study was carried out among 120 adopter and non- adopter farmers of Super Seeder farm technology. The study was carried out in the rural areas of 4 blocks of the district namely Bhuna, Bhattu Kalan, Ratia, and Fatehabad where maximum number of farmers had adopted Super Seeder farm technology. The total of 60 Super Seeder adopter farmers and 60 non-adopter farmers were selected. Interview schedule was prepared to collect the desired information as per objectives of the study. Data were collected with survey method with the help of well-structured interview schedule. Statistical techniques like frequency, chi square, weighted mean scores and rank order were applied as per the objectives of the study. Level of adoption of Super Seeder of the farmers was measured by developing an index and scores of each farmer was calculated by taking into account 4 parameters like, I- Land holding (up to 1 ha–score 1,1-2 ha - score 2,2-4 ha score 3 and 4- 10 ha score 4), II- income (Rs.200000 - 300000- score 1,Rs.300000 - 4,00,000- score 2 and above Rs. 4,00,000- score 3), III- years of adoption (up to 2 years score 1and more than 2 years score 2), IV- area under technology (up to 2 ha score 1,2-4 ha score 2 and 4 - 10 ha as score 3 were given. The total index score of each farmer was computed and categorized as low level adoption, medium level adoption and high level of adoption.

RESULTS AND DISCUSSION

Adoption level of the farmers: There was high level of adoption among farmers regarding Super Seeder which constitute of 53.33 per cent followed by medium and low level of adoption i.e. 26.67 per cent and 20.00 per cent respectively

Association between socio-economic variables and adoption level of super seeder: Age was significantly associated with adoption rate. More than half of the middle aged farmers (53.33%) have high adoption level whereas farmers above 50 years of age had low level of adoption (25%). Level of education have a significant association with level of adoption as farmers educated till senior secondary and above (46.67%) had high level of adoption whereas farmers educated up to middle school had a low level adoption rate (35%). Subsidiary occupation of family also has an impact on adoption level. Adoption level was high among 70% of the farmers who had an income source from business and services whereas, 38.46 % of farmers who did not have any subsidiary occupation had low level of adoption. Size of land holdings also have a signification association and level of adoption higher among farmers (62.50%) having annual income above 3,00,000 whereas, farmers (60%) with income between Rs.75,000 - 1,50,000 had a low level of adoption rate. There was significant association of social participation, mass media exposure and socio-economic status with adoption level. Farmers with nil social participation had adoption level (57.69) while adoption level was high among farmers (64%) with medium level of mass media exposure. Farmers with medium socio economic status had high level of adoption (62.50%) The farmers belonging from low socioeconomic status (53.84%) had low level of adoption. Kathpalia *et al*. (2022) also reported that age was significantly associated with knowledge level. In young age group high level of adoption (54.16%). Education and land holding were also d significantly associated with knowledge level of Super Seeder adopter farmers.

Cumulative socio economic impact of adoption of Super Seeder: Overwhelming majority of the medium size land holding farmer (85.71%) reported increase in good liasioning with extension officials and increased expenditure on performance of social ceremonies like marriage, death ceremonies and other social occasions (Table 2). More than fifty per cent of the small (55%) and marginal farmers (54.54%) adopter farmers reported increase in investment on quality education of children. Increase in decision making powers and in savings was reported by 71.71% of the medium land holders. Increase in agricultural land on lease and increase in mass media exposure was opined by medium land holders (57.14% each) while increase in social status was reported by medium (85.71%), semi medium (72.72%), small (55.00%) and marginal (36.36%) adopter farmers. Malik et al (2004) observed that earlier sowing improves the ability of wheat to compete against its major weed Phalaris, which was responsible for lower wheat yield and herbicide resistance. Increase in wheat as well as rice yield in next season due to residual effect of straw was also reported by the farmers.

Table 1. Association between socio-economic variables and adoption level of farmers (n=60)

Socio-economic variables	Adoption level			
Age	Low	Medium	High	Total
up to 35 yrs.	7 (38.89)	2 (11.11)	9 (50.00)	18 (30.00)
35˚ to 50 yrs.	2 (6.67)	12 (40.00)	16 (53.33)	30 (50.00)
above 50 yrs.	3 (25.00)	2 (16.67)	7 (58.33)	12 (20.00)
Total	12 (20.00)	16 (26.67)	32 (58.33)	60(100)
x^2 *Cal*=10.20*				
Caste				
General caste	8 (16.67)	15 (31.25)	25 (52.08)	48 (80.00)
Backward class	4 (33.33)	1 (8.33)	7 (58.34)	12 (20.00)
x^2 *Cal*=3.29				
Level of Education				
No formal schooling	1 (10.00)	1 (10.00)	8 (80.00)	10 (16.67)
Up to Middle	7 (35.00)	3 (15.00)	10 (50.00)	20 (33.33)
Senior Secondary and above senior secondary level	4 (13.33)	12 (40.00)	14 (46.67)	30 (50.00)
x^2 *Cal*=9.10*				
Subsidiary occupation of the family				
Nil	10 (38.46)	8 (30.77)	8 (30.77)	26 (43.34)
Business and services	1 (5.00)	5 (25.00)	14 (70.00)	20 (33.33)
Custom hiring	1 (7.14)	3(21.43)	10 (71.43)	14 (23.33)
x^2 *Cal*=12.55*				
Size of land holdings				
Marginal (up to 1 ha)	6 (54.54)	4 (36.36)	1 (9.10)	11 (18.33)
Small (1-2 ha)	2(10.00)	4 (20.00)	14 (70.00)	20 (33.33)
Semi-medium (2-4 ha)	3 (13.64)	6 (27.27)	13 (59.09)	22 (36.67)
Medium (4-10 ha)	1 (14.29)	2 (28.57)	4 (57.14)	7 (11.67)
x^2 *Cal*=14.09*				
Type of family				
Nuclear	6 (18.75)	12 (37.50)	14 (43.75)	32 (53.33)
Joint	6 (21.43)	4 (14.28)	18 (64.29)	28 (46.67)
x^2 *Cal*=4.25				
Size of family				
Up to 4 members	8 (32.00)	6 (24.00))	11 (44.00)	25 (41.67)
5-8 members	3 (11.54)	8 (30.76)	15 (57.70)	26 (43.33)
Above 8 members	1 (11.11)	2 (22.22)	6 (66.67)	9 (15.00)
x^2 *Cal*=4.18				
Annual Income(Rs.)				
Rs.2,00000 - 3,00000	6 (60.00)	2 (20.00)	2 (20.00)	10 (16.67)
Rs.3,00000 - 4,00000	4 (15.39)	7 (26.92)	15 (57.69)	26 (43.33)
Above Rs. 4,00,000	2 (8.33)	7 (29.17)	15 (62.50)	24 (40.00)
x^2 *Cal*=12.68*				
Social organization participation				
No organization participation	2 (11.11)	7 (38.89)	9 (50.00)	18 (30.00)
One organization participation	3 (11.54)	8 (30.77)	15 (57.69)	26 (43.33)
More than one organization participation	7 (43.75)	1 (6.25)	8 (50.00)	16 (26.67)
x^2 *Cal*=9.99*				
Mass media exposure				
Low (4-6)	6 (50.00)	4 (33.33)	2 (16.67)	12 (20.00)
Medium (07-09)	4 (16.00)	5 (20.00)	16 (64.00)	25 (41.67)
High (10-12)	2 (8.70)	7 (30.43)	14 (60.87)	23 (38.33)
x^2 *Cal*=11.61*				
Socio-economic Status				
Low (5-8)	7 (53.84)	3 (23.08)	3 (23.08)	13(21.67)
Medium (09-12)	3 (12.50)	6 (25.00)	15 (62.50)	24 (40.00)
High (13-16)	2 (8.69)	7 (30.44)	14 (60.87)	23(38.33)
x^2 *Cal*=12.65*				

*Significant at 5% level of significance , *Figures in parentheses indicate percentage

Table 2. Cumulative socio-economic impact of super seeder on farming families (n = 60)

Socio-economic impact	Marginal farmers 11 (18.33)	Small farmers 20 (33.33)	Semi-medium farmers 22 (36.67)	Medium farmers 7 (11.67)	Total n=60
Good liasioning with extension officials	4 (36.36)	13 (65.00)	18 (81.81)	6 (85.71)	41 (68.33)
Increased expenditure on performance of social ceremonies like marriage, death	8 (13.33)	12 (60.00)	12 (54.54)	3 (85.71)	35 (58.33)
Increase in Investment on quality education of children	6 (54.54)	11 (55.00)	10 (45.45)	2 (28.57)	19 (31.66)
Increase in decision making powers	5 (45.45)	13 (65.00)	13 (59.09)	5 (71.42)	36 (60.00)
Increase in income	7 (63.63)	7 (35.00)	14 (63.63)	5 (71.42)	33 (55.00)
Increase in Social participation	3 (27.27)	4 (20.00)	13 (59.09)	2 (28.57)	22 (36.66)
Increase in household assets	5 (45.45)	2 (10.00)	8 (36.36)	1 (14.28)	16 (26.66)
Increase in quality of medical treatment	3 (27.27)	8 (40.00)	7 (31.81)	-	18 (30.00)
Increase in agricultural land on lease	-	4 (20.00)	11 (50.00)	4 (57.14)	19 (31.66)
Increase in mass media exposure	6 (54.54)	13 (65.00)	10 (45.45)	4 (57.14)	32 (53.33)
Increase in social status	4 (36.36)	11 (55.00)	16 (72.72)	6 (85.71)	37 (61.66)

Responses were multiple, Figures in Parentheses indicate percentage

CONCLUSION

In order to deploy inputs without affecting the environment, it is essential to make the agricultural sector sustainable. In addition to providing the farmers with numerous benefits, the Super Seeder resolves a significant issue. As a result, managing the stubble becomes easy and convenient for the farmer as there is no longer of need to burn crop residue. Super Seeder is the most productive tool for placing wheat in paddy fields without burning straw in order to maintain soil nutrition value also.

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Utilization of Medicinal Plants for Diarrhea in Ukhrul District, Manipur

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Abstract**:** The *Tangkhul* Naga tribe predominantly inhabits the district of Ukhrul, located in the eastern part of the state of Manipur. The people of this hilly region use medicinal herbs to treat various diseases and ailments. A recent survey conducted from 2018 to 2019 among the *Tangkhul* community revealed use of 45 species of angiosperms, 43 genera and 35 families, for the treatment of diarrhea. This information was gathered through structured questionnaires and consultations with elders and *Tangkhul* practitioners. Some of the effective plant species used by *Tangkhul* practitioners to treat diarrhea include *Allium ascalonicum* L., *Cynodon dactylon* (L.) Pers., *Elsholtzia strobilifera* Benth., *Lantana camara* L.*, Psidium guajava* L., *Rhus javanica* L., and *Tinospora cordifolia* auct. The documentation of medicinal plants for diarrhea treatment not only provides valuable insights into traditional healing practices but also has implications for the conservation and sustainable utilization of the region's floral diversity.

Keywords**:** *Tangkhul,* Sustainable, Diarrhea, Ukhrul, Manipur

Diarrhea is an endemic disease in many of developing Asian countries, considered one of the major public health concern that leads epidemic cause of high degree of morbidity and mortality in rural communities. Diarrhea can be caused by a variety of bacterial, viral and parasitic organisms and infection spreads through contaminated food or drinking water, or from person to person as a result of poor hygiene (WHO 2015). It is one of the most common diseases for all age groups and decrease the absorption of fluid and thus a loss of electrolytes particularly Na+ and water (Rang et al 2003). Ukhrul, nestled in the picturesque hills of Manipur, India, serves as the ancestral homeland of the *Tangkhul* Naga tribe covering an expansive area of approximately 2,600 km^2. This region boasts a rich tapestry of flora, much of it cloaked in lush forests. The livelihoods of the *Tangkhul* people predominantly revolve around agriculture, and have deep understanding of the medicinal herbs that flourish in their environment. Rooted in oral traditions passed down through generations, these traditional healing practices form an integral part of the community's healthcare system. Furthermore, Ukhrul's unique ecological and cultural context offers a distinct perspective on the challenges and solutions related to diarrhoea management within this vibrant community. There are studies on the use of traditional medicine in North-East India (Borthakur 2013, Gairola et al 2013, Panmei et al 2019, Singh et al 2019, Baidya et al 2020, Salam et al 2021, Asangla et al 2022, Das et al 2023). An effort was made to catalog the plants utilized by the inhabitants of the *Tangkhul* community for the treatment of diarrhea.

MATERIAL AND METHODS

The survey was conducted among the *Tangkhul* Naga tribe in 2018-2019. Key informants, included elders and traditional practitioners, which were interviewed and provided with structured questionnaires to collect information about various aspects of traditional medicine. Local names, preparation methods, and the plant parts used were also documented. The specimens were prepared following the procedures outlined in Jain and Rao (1977), and their identities were verified using various sources, including Kanjilal et al (1934-1940) and Parabia and Reddy (2002). All the plants catalogued had their names and family classifications cross-referenced with the website www.theplantlist.org. Voucher specimens are available at the herbaria of Nagaland University in Lumami (Department of Botany) and Manipur University in Imphal (Department of Life Sciences).

RESULTS AND DISCUSSION

Allium ascalonicum L., *Lantana camara* L., *Psidium guajava* L., *Rhus javanica* L., *Tinospora cordifolia* auct. Non Willd., and *Paris polyphylla* Sm. documented plant species traditionally recognized for their effectiveness in alleviating symptoms of diarrhea. The utilization of various plant parts, including leaves, roots, rhizomes, and stems. This

Table: 1. Medicinal plants used in Diarrhea by the *Tangkhul* Naga tribe of Ukhrul District of Manipur

Botanical name [Family]	Vernacular name	Parts used	Mode of use
Aegle marmelos (L.) Corr [Rutaceae]	Heirikhagok	Fruit	Unripe fruit is wrapped in mud and roasted to make a solution with a spoonful of sugar in water and given in diarhea.
Alangium chinensis (Lour.) Harms [Cornaceae]	Kokan	Leaf	Decoction of leaves with ½ spoon sugar and little salt given in diarrhea till motion control.
Allium ascalonicum L. [Amaryllidaceae]	Meitei-Tarui	Bulb	Fresh bulb juice with water is taken twice until it stop.
Allium cepa L. [Amaryllidaceae]	Tarui	Bulb	Decoction of bulb 200ml is given in diarhea.
Artemisia nilagirica (C.B. Clarke) Pamp. [Asteraceae]	Harana	Whole plant	A handful of fresh leaves juice mixed with diluted honey (1-2 teaspoonful) is taken orally once daily for a week to cure diarrhea.
Artocarpus heterophyllus Lam. [Moraceae]	Theibo	Root	Decoction of root 20ml is given twice a day for five days to cure diarrhea
Artocarpus lakoocha Roxb. [Moraceae]	Heirukothong	Bark	Decoction of bark 50ml is given twice a day for five days to cure diarrhea
Bryophyllum calycinum Salisb. [Crasulaceae]	Manahidak	Leaf	Juice extracted from the leaves mixed with 3g seeds powdered of *Piper nigrum* is prescribed 2 teaspoon twice daily for three days in diarrhea
Callicarpa arborea Roxb. [Verbenaceae]	Chicothing	Bark	Boiled extract of the bark is prescribed against diarrhea.
Cannabis sativa L. [Canabinaceae]	Ganja	Leaf	The leaves and flowers are used in diarrhea
Catharanthus roseus (L.) G. Don [Apocynaceae]	Kundalei	Leaf	Half glass (adult) from boiled extract of 30 leaves in one litre of water is given three times daily for 1-3 days against diarrhea.
Centella asiatica (L) Urban [Apiaceae]	Kongrihan	Whole plant	Fresh juice of *Centella asiatica* and *Oxalis corniculata* are mixed in equal proportion with one teaspoonful of honey about 1/2 glass is given thrice daily for 3 or 4 days in frequent diarrhea
Cynodon dactylon (L.) Pers. [Poaceae]	Tingthou	Whole plant	Fresh extract juice with honey 10ml is given twice a day to cure diarrhea
Drymaria cordata (L.) Willd. ex Schult. [Caryphyllaceae]	Biviyena	Whole plant	Boiled extract of the whole plant is prescribed 1/2 glass twice daily for 2 or 3 days in diarrhea
Ehretia acuminata R.Br [Boraginaceae]	Magingran	Root	Decoction of 50ml is given twice a day for five days to treat diarrhea
Elsholtzia strobilifera Benth. [Lamiaceae]	Yongpa	Inflorescene	The inflorescence with rhizome of *curcuma longa* is boiled and the extract obtained is prescribed in diarrhea
Emilia sonchifolia (L.) DC. [Asteraceae]	Revival	Whole plant	The fresh root extract of about 2-3 teaspoon is also given twice a day for 3 days in diarrhea
Eryngium foetidum L. [Apiaceae]	Lam sachikom	Leaf	A handful of fresh leaves are boiled with one litre of water and the filtrate decoction 1/2 cup is administered twice daily for 3 days against diarrhea
Ficus tsjakela Burm.f.[Moraceae]	Sangleikokna	Tender shoot	Boiled extract of tender shoot is given in diarrhea
Justicia adhatoda L. [Acanthaceae]	Sipchang	Leaf	Fresh leaves 6 or 7 are crushed and the extract of about 2 teaspoon is mixed with honey and given thrice daily for 3 days in diarrhea
Lantana camara L. [Verbenaceae]	Nganam shirong	Leaf	A decoction of three teaspoons of fresh leaves is taken three times per day to alleviate severe diarrhea
Litsea sebifera Pers. [Lauraceae]	Khamarinarong	Leaf	200g bark is boiled in 1.5litres and the decoction 250ml is given thrice daily for 3 days in diarrhea
Lygodium japonicum (Thunb.) Sw. [Lygodiaceae]	Chao-ma-libna	Whole plant	Decoction of the plant 100ml is prescribed twice a day for a week in diarrhea
Lysimachiaparviflora baker. [Primulaceae]	Kengoi	Whole plant	Boiled extract of whole plant is given in diarrhoea
Mentha spicata L. [Lamiaceae]	Suiruihan	Whole plant	Three teaspoonfuls of leaf juice are mixed with one spoon of honey and given orally in diarrhea
Melastoma malabathricum L. [Melastomaceae]	Yachubi	Rhizome	A cup of rhizome or fruit decoction is given twice daily for three days in diarrhea
Musa paradisiaca L. [Musaceae]	Mothei	Petiole	The crushed extract of the fleshy petiole (3-5ml) is also taken 181 in diarrhea
Mussaenda roxburghii Hook. f. [Rubiaceae]	Kongrawon	Leaf	Tender leaves cooked with lata fish is prescribed in diarrhea.

Cont...

Table: 1. Medicinal plants used in Diarrhea by the *Tangkhul* Naga tribe of Ukhrul District of Manipur

Botanical name [Family]	Vernacular name	Parts used	Mode of use
Ocimum canum Sims. [Lamiaceae]	Sari	Leaf	Leaf juice with honey is prescribed in diarrhea
Parkia timoriana (DC.) Merr. [Fabaceae]	Yongchak	Bark	The decoction of the bark (10-15ml) is given twice daily for three days to cure diarrhea
Paris polyphylla Sm. [Melanthiaceae]	Nayong hanghor	Rhizome	Decoction of the leaf is administered in diarrhea
Persicaria chinensis (L.) H.Gross [Polygonaceae]	Hannahan	Leaf	While boiled extract of the root is also given in diarrhea
Psidium guajava L. [Myrtaceae]	Pungdonrong	Leaf	Crushed extract of the tender leaf or boiled extract of the root is mixed with a tablespoon of honey and given in diarrhea
Punica granatum L. [Lythraceae]	Kaphoi	Leaf	A half cup decoction of the outer skin of fruit is given twice daily for 3 days in diarrhea
Quercus serrata Murray [Fagaceae]	Hoktheithing	Seed	Roasted seeds are used in diarrhea.
Rhododendron arboretum Sm. [Ericaceae]	Kokliwon	Flower	Fresh petals are eaten in diarrhea
Brucea javanica (L.) Merr. [Simaroubaceae]	Khamkhuithei	Tender shoot	Tender shoot is eaten raw in diarrhea
Sida acuta Burm. [Malvaceae]	Uhan	Leaf	Juice obtained by crushing the leaves, 2-3 teaspoons, is mixed with one spoon of honey and given twice daily in diarrhea
Scutellaria discolor Wall. ex Benth. [Lamiaceae]	Yenakha	Leaf	Half a glass of leaves extract is given with a spoon of honey twice a day for a week to cure diarrhea
Solanum anguivi Lam. [Solanaceae]	Kapkhathei	Fruit	Fruits are crushed with honey and given in diarrhea
Spondias pinnata Kurz. [Anacardiaceae]	Khursongthei	Bark	About 250g bark with 2 litres of water is boiled and the decoction 300ml twice daily for 3 days is prescribed in diarrhea.
Stephania japonica var. discolor (Blume) Forman [Menispermaceae]	Koubru yai	Leaf	The juice obtained by pounding the leaf 2 teaspoon is mixed with honey and prescribed twice daily for 3 days in diarrhea
Syzygium cumini (L.) Skeels [Myrtaceae]	Chomshathei	Bark	A half cup decoction of the seeds is given twice daily for 3 days in diarrhea
Tamarindus indica L. [Fabaceae]	Mange	Bark	Decoction of bark is given twice daily for a week to cure diarrhoea
Tinospora cordifolia (Willd.) Hook.f. & Thomson [Menispermaceae]	Ningthoukhongli	Stem	Fresh stem juice (3-4ml) is taken twice daily for 3 days against diarrhea

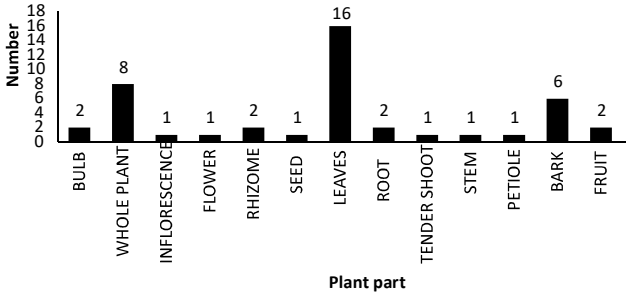

Fig. 1. Medicinal plant species as used through its different plant parts

demonstrates the comprehensive knowledge and resourcefulness of the *Tangkhul* people in using different plant components for their healthcare needs. The *Tangkhul* people harnessed the medicinal benefits of these plants through traditional techniques of preparation and administration, including decoctions, infusions, and poultices. The cultural wealth and distinctive medical system of the *Tangkhul* Naga are reflected in the diversity of their customs.

This study documented the pharmacological effects of 45 plant species belonging to 35 families and 43 genera for diarrhea treatment. Lamiaceae was the most represented family, with four species, followed by Moraceae with three species. There were two species each from Amaryllidaceae, Asteraceae, Verbenaceae, Apiaceae, Fabaceae, Myrtaceae, and Menispermaceae, and one species each from 24 other families. The *Tangkhul* people's ability to utilize various plant components underscores their extensive knowledge and resourcefulness. Furthermore, this research emphasizes the importance of conserving and sustainably using these valuable plant resources. Cultivating medicinal plants in home gardens and agricultural areas not only aids conservation efforts but also supports the economic development of the *Tangkhul* community. Thus, the survey of medicinal plants used for diarrhea treatment in the Ukhrul district, Manipur, offers valuable insights into traditional healing practices and underscores the need for the conservation and sustainable utilization of the region's diverse flora.

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Impact of Climate Change and Biological Factors on Agriculture in Western Himalaya- People's Perception

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***Abstract*:** Climate change is one of the most important environmental challenges that affect all the natural ecosystems of the forest and agriculture. This article provides a brief overview of the impacts of climate change and other biological factors on agriculture in the western Himalayan region based on the perception of local inhabitants and researchers. In this study, questionnaire survey was conducted in which 10% of total population was interviewed from 7 villages of Almora district, Uttarakhand, west to their Himalaya. According to responses, significantly higher proportion of respondents (42.85%) perceive rise in temperature as major sign of climate change and consider deforestation (35.70%) as major cause of this change. Respondents of the area experienced significantly higher effects of climate change from 10 to 20 years (67.14%). There has been a significant decrease in the productivity of the main 10 crops such as *Triticum aestivum*, *Echinochloa frumentacea*, *Oryza sativa*, *Zea mays*, *Glycine max*, etc. The comparative study of crops was done between 1989 and 2019, where average production of *Triticum aestivum* (5027.84 kg/ha) and *Echinochloa frumentacea* (4244.02 kg/ha) continuously decreased during the period of ten years. The major future consequences of climate changes are increasing in agricultural loss and water loss/ scarcity. To mitigate the impact of climate change and other biological factors are awareness and reforestation and sustainable utilization of resources, forest management and flexible government policy.

***Keywords*:** Climate change, Biological factors, People's perception, Kumaun Himalaya

The Indian Himalayan region is home to about 51 million people, practicing hill agriculture in fragile and diverse ecosystems, including species-rich forests. The region has a considerable hydropower potential and feeds numerous perennial rivers which depend upon the sustainable existence of glaciers (GoI 2010, DST 2012). Agriculture forms the main livelihood source for 70% of the Himalayan region, and was significant contributor to the household food security of the local communities (Tiwari and Joshi 2015, Hussain et al 2016). However, the current discourses on agriculture in the Himalaya have recurrently highlighted the on-going agrarian distress in the region manifested by deteriorating land productivity (Ojha et al 2017), declining yield in the last decades (Negi et al 2012), exacerbating food insecurity (Gautum and Andersen 2016) and deepening poverty (Gentle and Maraseni 2012). Farmers, in recent times, have been a victim of unprecedented climate-induced social, economic and environmental transitions in the region (Barua et al 2014, Macchi et al 2014). Climate change impacts are set to profoundly change global ecological and social systems, bringing about fundamental changes to human behavior (Evans 2019). Nonetheless, studies have demonstrated evidence that communities who are more in touch with their surroundings are able to accurately detect environmental changes, such as seasonal temperature and weather fluctuations (Poudel and Duex 2017, Uprety et al 2017). In addition, high dependence on monsoons, unavailability of irrigation facilities and small landholdings intensify the sensitivity of Himalayan farmers (Kuniyal 2003, Rasul 2014). The climate-related shift in production capacity has led to changes in crop yield, reduced crop diversity and increased pest-invasion in the region (Negi et al 2012, Kaul and Tornton 2014). In the previous years, agriculture sector in India has been hard hit by extreme natural calamities such as droughts, floods, heat waves and cyclones (Goswami et al 2006) causing fall in the productivity of food grains, aggravating the food vulnerability of marginal and small farmers, leading to food insecurity and poverty (Birthal et al 2014). Although the weather conditions affect the crop productivity to a considerable extent, soil fertility, varieties of seeds, pests and diseases are some of the other factors that are dependent on climatic variations (Khan et al 2009). Moreover, that too clusters of monkeys and pigs living in areas closer to agricultural fields and that the monkeys and pigs populations were increasing (Sahoo and Mohnot 2014). The objective of the study are: The objective of the study were to assesses the impact of climate change and biological factors on agriculture crops of the study area, reduction in

crop production and to predict the future impacts of climate change.

MATERIAL AND METHODS

The study area, Almora district, Uttarakhand is located at 79° 44' 35" E longitudes and 29° 32' 55" N latitudes. Appropriate semi structural questionnaire formats were developed for gathering the perceptions of people regarding the impacts of biotic and abiotic factors on crop production. A total of 7 villages of Hawalbagh block namely Syuna, Jyoli, Katarmal, Kaneli, Chalar, Udiyari, and Pakhura were selected for the questionnaire-based surveys. An average of 10% of questionnaires was filled up with the help of out of total families (households) present in each village. The information was collected after a long session of discussions with the expected families such as what was the impact of abiotic factors (temperature, droughts, precipitation, etc.) and how they influence your local biodiversity, water resources, and crop productivity. Moreover, the impact of biotic factors (diseases, pest pathogens, monkeys, boars and pigs) on crop productivity was also investigated through questionnaires during the field investigation. After the collection of complete information, their suggestions, recommendations, and future strategies were also gathered regarding the mitigations and adaptation to fight against these challenges, and then the data was compiled and documented.

Data analysis: The survey data collected were analyzed using one-way analysis of variance to assess the distribution of sample means from observations at a 95% confidence level. The IBM SPSS 25 version was employed for Descriptive statistical analysis of various qualitative and quantitative parameters.

RESULTS AND DISCUSSION

Response on climate change: The respondents of the study area understand the concept of climate change and how this change has impacted their lives. According to their response, a significantly higher proportion of respondents (42.85%) perceive a rise in temperature as a major sign of climate change, followed by erratic rainfall and low snowfall (24.89%), longer drought spells (19.57%), shifting in monsoon pattern as well as fluctuating weather conditions (12.69%) (Table 1). Similarly people's perception-based findings were also reported in the Himalayan region (Baul et al .2013). Local communities in the Himalayan region are seen to have widespread indigenous knowledge about climate change impacts and they have been successfully coping with these changes (Byg and Salick 2009, Chaudhary et al 2011). And have reported various indicators of climate change like drying up of water springs, early flowering and budburst in some species, seasonal change in rainfall, shifting and adaptation of natural vegetation, pest disease attack, early crop maturity, loss of livestock population, and water scarcity (Negi et al 2017). In general farmer's thoughts and experiences are congruence with scientific studies (IPCC 2007). The study area indicates that long-term changes in surface air temperature over India during the twentieth century also broadly agree with earlier assessments (Rai et al 2012, Vinnarasi et al 2017, Kothawale et al 2016, Kulkarni et al 2017, Srivastava et al 2019).

Response on the main cause of climate change: The respondents of the study area state that the main causes of climate change are deforestation (35.70%) followed by forest fires (27.15%), urbanization and industrialization (25.72%), (Table 2). However, no significant variation was exhibited among the main causes of climate change as reported by respondents. The related scientific report indicates that climate change is caused by natural phenomena and anthropogenic activities (Montzka 2011, Stem 2014). The respondents of the area experienced significantly higher effects of climate change from 10 to 20 years (67.14%), followed by about 20 to 30 years (16.71%) and from 10 years (14.28%), while 1.87% respondents did not give any response (Table 1c). Similarly, previous people perception study indicates that increase in annual temperature and reduction in annual rainfall, with greater unpredictability in comparison to 30 years ago (Baul et al 2013). The previous scientific study indicates that the Kosi River basin also examined the rainfall status for the past 34 years (1981-2015) and decreasing trend was observed (Shrestha, 2019). Similarly, the HKH experienced a significant decline in snowfall (Ren et al 2015, You et al 2015) and glacial area (Kulkarni and Karyakarte 2014, Wester et al 2019) in the last 4-5 decades. Most of the Western Himalayan (WH) stations recorded a significant warming trend from 1975 onwards (Dimari and Das 2012, Negi et al 2018). Significant rise in surface temperature was observed throughout the HKH region during the past six decades (Kulkarni et al 2013, Rajbhandari et al 2016).

People's responses to the impact of climate change on agriculture: According to the responses of the people in the study area, the impact of climate change has been seen in agriculture is mostly witnessed to low crop productivity (37.98%) and early maturation (22.04%) (Table 2a).The main impact of climate change was observed in agriculture production attributed to lack of rain, the presence of insects, pests, and unwanted invasion. Similar findings were also reported on the basis of people perception's (Suberi et al 2018, Dalal et al 2018). Intergovernmental Panel on Climate

Change (IPCC)'s report shows that the crop yield in many countries of Asia has declined, partly due to the rising temperature and extreme weather events and rainfall variability (Cruz et al 2007). The changes in climatic events such as temperature and rainfall significantly affect the yield of crops (Mahi 2021). The previous study indicates that, historically, low precipitation events have been attributed to many of the largest falls in crop productivity (Kumar et al 2004, Shivakumar et al 2005); agriculture is considered the most endangered activity, adversely affected by climate changes (Ali et al 2019). Furthermore, climate change-induced diseases and pests have also negatively impacted crop yields (Bhatta et al 2015), thus contributing to a reduced agricultural output (Paudel et al 2016).

Impact of other biological factors on agriculture: Apart from climatic parameters, some factors affect crop productivity as per respondents included mainly animal attacks, most importantly monkeys (45.72%), wild boars (30%), rodents (14.28%), and birds (10%) (Table 2b). The respondents agreed that they observed the effect of biotic factors most significantly, (65.72%) respondents feel it from 15 years, then (18.56%) from 10 years, (11.43%) from 5 years and (4.29%) respondents from 20 years. Similar findings were also reported by earlier workers crop damaged by rodents (Parshad 1999, Sridhara and Tripathi 2005), and wild boars damaged crops (Rao et al 2002, Dalal et al 2018). In other studies, outside of the region, people also reported an increase in the incidences of crop damage by wild animals, including monkeys, boar, deer, bears, and rodents due to an increase in their population. Animals that engage in these activities are often labeled 'crop raiders' and their actions as 'crop raiding' (Humle & Hill 2016). Crop raiding is commonly used to mean the action of, or results of, wild animals damaging standing crops by feeding on or trampling them (Hill 2017).

Reduction in agricultural production: According to the perception of the people, there was a significant decrease in the productivity of the main 10 crops due to climate change and other responsible factors like monkeys, boars, rodents, and birds. A comparative study of crops was done between 1989 and 2019, the production of *Triticum aestivum* was 5027.84 kg/ha, now reduced to 2009.14 kg/ha between 2010 and 2019. There has been a reduction of up to 3018.7 kg/ha in *Triticum aestivum* production. *Echinochloa frumentacea*

Table 1. People's response regarding to climate change and causes of climate change

Response	Rising temperature	Erratic rain & low snowfall	Long drought spells	Shifting monsoon period
Understanding of climate change				
Proportion (%)	42.85±0.69[a]	24.89±0.52[b]	19.57±0.27[c]	12.69±0.21[d]
		F= 4.57 p= 0.04*		
Main causes of the climate change				
Response	Deforestation	Forest Fire	Urbanization & industrialization	Motor vehicles and others
Proportion (%)	35.70±0.39	27.15±0.35	25.72±0.36	11.43±0.11
		F= 2.65 p= 0.06		
Villagers response to climate change from				
Response	10 – 20 years	20 – 30 years	< 10 years	No climate change
Proportion (%	67.14±1.25[a]	16.71±1.01[b]	14.28±0.79	1.87±0.02
		F= 21.80 p< 0.001***		

Table 2. Responses of people to the impact of climate change and other responsible factors on agriculture

Impact of climate change on agriculture					
Response	Low crop productivity	Early maturation	Reducing shape and size	Invasion of alien plant species	Diseases, pest and pathogen
Proportion (%)	37.98±0.99[a]	22.04±0.87[b]	14.64±0.55[c]	13.29±0.36[c]	12.05±0.44[c]
				F= 3.77	p< 0.01**

Other responsible factors which affect the crop productivity of people				
Response	Monkeys	Wild boars	Rodents	Birds
Proportion (%)	45.72±2.23[a]	30.10±2.03[b]	14.28±0.85[c]	10.23±0.26[d]
			F= 7.93	p< 0.001***

Table 3. Showing the average reduction in crop production (Kg/ha)

Major crops	Average crop production (Kg/ha)			Average reduction in crop production (Kg/ha)
	1989- 1999	2000 -2009	2010-2019	1989-2019
Wheat (*Triticum aestivum*)	5027.84	3225.47	2009.14	3018.7
Rice (*Oryza sativa*)	3991.88	3244.92	1505.86	2468.88
Maize (*Zea mays*)	2098.83	1472.47	777.84	1320.99
Maduwa (*Eleusine coracana*)	4014.30	2407.78	1759.49	2254.81
Madira (*Echinochloa frumentacea*)	4244.02	2260.28	1259.70	2984.32
Kala bhatt (*Glycine soja*)	3020.69	1616.48	1010.55	2010.14
Soya bean (*Glycine max*)	3759.17	2020.60	1403.21	2355.96
Gahat (*Macrotyloma uniflorum*)	1500.38	1003.07	302.96	1197.47
Urad (*Vigna mungo*)	1159.54	711.57	477.97	1145.26
Masoor (*Lens esculenta*)	1282.62	912.38	507.76	774.86

was gradually decreased and the production between 2010 and 2019 was only 4244.02 kg/ha. Thus, a decrease of up to 2984.32 kg/ ha was observed in the production of *Echinochloa frumentacea*. Earlier scientific studies indicate that, in recent decades, the area under traditional crops has drastically declined (>60%), and many of the crops are at the verge of extinction, such as *Glycine spp., Hibiscus sab-dariffa*, *Panicum miliaceum*, *Perilla fruitescens*, *Setaria italica*, *Vigna spp*. (Maikhuri et al. 2001; Negi and Joshi 2002). Currently, climate change has a negative influence on food security as various predictions indicate a significant decrease in the productivity of different crops (Thompson et al., 2010). Many studies already found that climate change can reduce the yield of wheat by 3.5 to 12.9% (Gammans et al 2017), of maize by 34.6 to 35.4% (Li et al 2014), and of paddy by 10 to 15% (Nelson et al 2009, Li et al 2018). The IPCC (2007) concurred that higher temperature is also the reason for reduction in cereals (e.g., rice and wheat) production especially in South Asian countries. Comprehensive review around the globe is pointing to clear evidence of a decline in the yields of important cereal crops under climate change conditions (Mall et al 2006, Lobel, and Gourdji 2012, Timsina and Humphreys 2006).

Future impacts of climate and suggestions of villagers to reduce these impacts: According to the people's responses, climate change will have more negative effects in the future. Most of these effects will result in loss of agriculture, followed by water scarcity, more drought, and migration of people, epidemics, and problems of inflation. While people suggested reduction strategies for impact of climate change and people provided some suggestions to reducing the impact of factors effecting crop productivity. The impacts of climate change are one of the greatest challenges the country is facing today and would continue to be so in the near future (Chhogyel and Kumar 2018). Many climate models have predicted a decrease in precipitation with an increase of dry periods (Maloney et al 2014, Chadwick et al 2016, Duffy et al 2015). The IPCC report projects that in the coming decade's climate changes will increase in all regions. For 1.5°C of global warming, there will be increased heat waves, longer warm seasons, and shorter cold seasons. At 2°C of global warming, heat extremes would more often reach critical tolerance thresholds for agriculture and health (IPCC 2021). In order to reduce the vulnerability impressions, people gave their important suggestions, the main ones being aware, afforestation, and conservation of water sources less use of oil gas and chemical fertilizers. Besides, the mixed cropping pattern is the best option for reducing the impact of climate change. This pattern has been started for few times by villagers.

CONCLUSION

Agriculture and livestock are one of the main livelihood sources of the marginal living people of the Himalayan region who are straightway exposed to climate and therefore most affected by the climatic variability. The respondents interviewed in the study area agreed to recognize that rises in temperatures, precipitation patterns, longer drought spells, and shifting monsoon patterns have been feeling for the previous twenty to thirty years. Moreover, respondents also believed that for some years the number of main wild animals like monkeys and boars is also increasing, which is causing more damage to agricultural production. Due to both these reasons, crop production has reduced drastically in the last ten to fifteen years, and some people have stopped growing these crops. Due to this, the economic and social conditions

of the people have also been deteriorated, which is not a good sign for the future. Respondents of the study area have given their valuable suggestions regarding reducing the impact and vulnerability to climate change and other responsible factors which included community awareness, adaptive measures, reforestation, conservation of water resources, and less use of oil-gas and chemical fertilizers.

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Pollinator Diversity and Foraging Behavior in Chayote (*Sechium edule* Jacq)

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***Abstract*:** Chayote (*Sechium edule* Jacq.) is one of the important cucurbitaceous vegetables prominently grown in the northeastern Himalayan states. These crops prevail abundantly across this region however acquire little knowledge of their pollination. Information on pollinators is crucial for any crop; therefore, the study was conducted in the farmers' field to study the pollinators of chayote. The diversity of insect visitors was studied by observing the random flowers. The temporal abundance, foraging speed, and foraging rate were studied by observing twenty different flowers for 10 minutes. A total of nine species were recorded from the order Hymenoptera of which 3 species belonged to Apidae, 3 wasp species belonged to Vespidae and 1 species belonged to Halictidae. Shannon's diversity index (H), Simpson's diversity index and species richness (Margalef) were recorded as 2.131, 0.8741 and 1.782 respectively. The study revealed a significant relationship between foraging speed, species, day hours and species X day hours, while there was a non-significant relationship between foraging rate, species and day hours. The overall pollinators observed was 258 where highest pollination occurred during 9-11 hrs. The least time was spent during 15-17 hrs (6.74 seconds) while the frequency of foraging rate was highest during 15-17 hrs (10.83 flowers/minute).

***Keywords*:** Pollinator, Diversity, Foraging behavior, Chayote

Pollination, a vital aspect of the reproduction of flowering crops is given the greatest importance (Ollerton et al 2011, Giannini et al 2015). About 75% of crop species are pollinated by animals most of which are insect pollinators (Choi et al 2015, Siregar 2014). Chayote (*Sechium edule*) is a perennial monoecious climber in the Cucurbitaceae family which is an excellent source of nutrition (Kumar et al 2016, Stephens 2018). In India, it is widely cultivated in West Bengal, Tamil Nadu, Himachal Pradesh and the entire northeastern region for its tender shoots, fleshy pear-shaped fruits and tuberous roots (Yadav et al 2005, Rai et al 2006). It is one of the major vegetable crop grown in Sikkim and is consumed by both humans and animals. However, due to unknown diseases and other factors, chayote production has declined drastically in recent years. It bears a monoecious flower that requires sufficient entomophilous pollination to produce a substantial yield (Mukherjee et al 2019). It has been reported unsuitable for the cultivation of chayote under a greenhouse structure as the fruits fail to develop and drop before reaching maturity. (Bomfin et al 2016, Widhiono 2015). Chayote is cross-pollinated crop both the pistillate and staminate flowers are rich in nectar that attracts a variety of pollinators (Rojas-Sandoval 2020). Stingless bees of the genus *Trigona* are primary and efficient pollinators while wasps are among the secondary pollinators of chayote (Arnold et al 2018, Lira Saade 2020). Apart from the above insects *Apis mellifera* is also reported to pollinate the chayote plant (Soma Alvarez and Nunez Grajales 2013, Ricketts et al 2008, Reilly et al 2020). Pollinators such as *Apis dorsata, Apis cerana, Apis florea*, and *Trigona sp.* pollinate chayote in Bangalore, India (Mukherjee et al 2019). In the eastern Himalayan region of India, there is no information on chayote pollinators except the Indian bee (*Apis cerana* Indica). Considering the importance of insects in pollination of Chayote, the present study was undertaken to study the diversity, species richness and foraging behavior of pollinators of Chayote (*Sechium edule*).

MATERIAL AND METHODS

Study area: Sikkim is a fully organic state of India with an area of 7096 sq. km. and stretching 112 and 64 km from north to south and east to west, respectively. However, the habitable area is only 2500 sq. km. This Himalayan state lies between 27.45° N and 28.9° N latitudes and 87.59° east and 88.60° E longitudes. It accounts for about 0.05% of the total population and 0.22% of the geographical area of the country. The study was conducted in farmer's field of seven villages namely, Burikhop (West Sikkim), Pakki Goan (West Sikkim), Budhang (West Sikkim), Tsong (West Sikkim), Sang (East Sikkim), Sumik Lingee (East Sikkim), and Dzongu (North Sikkim) (Fig. 1).

Data collection: Visitors were captured using fine mesh

sweep nets and immobilized using ethyl acetate vapours. Experts from various universities and institutes identified the collected insect pollinators. Daily observations on random flowers were made to study the diversity of insect visitors. During the full bloom period, the temporal abundance, foraging speed and foraging rate of different insect visitors/pollinators were studied in twenty different chayote flowers for 10-minute intervals at 9:00-11:00 hrs, 12:00-14:00 hrs, and 15:00-17:00 hrs. Twenty individual species were observed to record the amount of time spent on each flower to study foraging speed, while foraging rate was recorded in terms of the number of flowers visited per minute through careful visual observation with a stopwatch (Dafni 2001).

Statistical analysis: The relative abundance of order, family, and species were used to calculate dominance. The Shannon diversity index (H'), Simpson Index, species richness (marglef) and evenness were calculated using the past 4 project software. The two-factor, completely randomized design was used to study variables such as foraging speed and rate. The two factors were species and day hours having 8 and 3 levels, respectively. Means were compared using the least significant difference test. The analysis was carried out with the help of the R package Doebio Research (Popat and Banukara 2020).

RESULTS AND DISCUSSION

A total of nine species were recorded, all belonging to the order Hymenoptera under 3 families of which 3 species belonging to Apidae (L*epidotrigona arcifera, Apis cerana, Bombus haemorroidalis*), five wasp species belonging to Vespidae (*Polistes carnifex*, *Eumenes fraternus*, *Pachodynerus sp.*, *Polybia sp.* and *Polistes Canadensis*), 1 species belonging to Halictidae (*Lasioglossum aeneiventre*) (Table 1). Rashmi et al (2014) also observed eight species of insects visitors of chayote flower belonging to the order Hymenoptera (Apidae, Halictidae, Specidae, Formicidae and Vespidae) and Diptera (Muscidae) of which major pollinator was *Trigona* sp. followed by *Apis cerena* belonging to order Hymenoptera.

Mukherjee et al (2019) found that *Apis cerana, Apis florea*, *Apis dorsata* and *Trigona* sp. are primary pollinators of chayote, all of which belong to the Hymenoptera order. Similarly, *Synoeca*, *Polybia,* and *Parachrataegus* wasps and smaller *Trigona* species are secondary pollinators. Similarly, Martínez-Bauer et al (202) recorded *A. mellifera* and *B. ephippiatus* are *S. edule* pollinators but also wasps such as *Polybia* species, *Polistes instabilis* and *V. squamosa*.

Vespidae was the most abundant family with six species contributing 51.54% of visitor abundance (Table 2). Among the pollinators species belonging to the vespidae, the highest relative abundance was recorded for *Polistes canadensis* (13.95%) followed by *Polistes carnifex* (13.57%) and *Pachodynerus sp.(9.30%)* and the least was *Eumenes fraternus* (5.81%). Family Apidae comprises 37.70% of relative abundance, where species *Apis cerana* recorded 17.83% abundance followed by *Lepidotrigona arcifera* (10.47%) and *Bombus haemorroidalis* (9.30%). *Lasioglossum aeneiventre* belonging to the Halticidae recorded, 10.85% of relative abundance. Among all the species irrespective of family the highest abundance was in species *Apis cerana* (17.83%) followed by *Polistes Canadensis* (13.95%) and *Polistes carnifex* (13.567%) *Lasioglossum aeneiventre* (12.36%). The least abundant was in *Eumenes fraternus* (5.81 %). This may be due to the wide domestication of *Apis cerana* by the farmers of Sikkim and its wide feeding preferences (Cui and Corlett 2016).

Shannon diversity index (H), Simpson diversity index, Berger-Parker index, and species richness (Margalef) values were 2.131, 0.874, 1.782, and 0.191, respectively (Table 3). This reflects the rich diversity of chayote, which is not dominated by a single species. This result is also reflected in the relative abundance of *Apis cerana*, which is followed by the other pollinator species. Bashir et al (2019) found a Shannon diversity index (H') of 3.97 and a Simpson diversity index of 0.93 in forest ecosystems. Alfawwaz et al (2022) reported a moderate Shannon diversity index (H') of 1.23. Eight pollinator species except *Eumenes fraternus* were identified as the main pollinators of chayote based on their abundance and foraging activity. Detailed observations were then made on these eight species. Pollinator foraging activity on chayote was greatly reduced during wind and intermittent rainfall but resumed again when conditions returned to normal. Sharma et al (2019) reported that the foraging activity of pollinators was negatively related to relative humidity and wind velocity. The highest relative abundance was recorded in *Apis cerana* (17.83%.), *Polistes Canadensis (*13.95%*), Polistes carnifex* (13.57%) followed by *Lasioglossum aeneiventre* (10.85%), and relative abundance was recorded in *Eumenes fraternus* (5.81%) (Table 4). Data on temporal variation in pollinator abundance (Table 5) showed that the highest number of insect visitors was recorded between 9:00-11:00 hrs (133 no.) followed by 12:00-13:00 hrs and 14:00-15:00 hrs. All the pollinator peak activities were observed between 9:00-11:00 hrs of the day and slowly decline towards evening. Thakur and Rana (2002) also found a significantly higher number of insect visitors during 9:00-10:00 hrs (3.88 insect/m^2/10 min) followed by 12:00-13:00 hrs and 15:00-16:00 hrs. Sharma et al (2019) also observed maximum bee visitors during 9:00-11:00 hrs, slightly low in 11:00-13:00 hrs and lowest in 15:00-16:00 hrs.

The higher activity of insect visitors during morning hours synchronizing with the opening of flowers was also reported by Sajjanar et al (2004). According to Widhiono (2015) humidity and light intensity also have a significant impact on pollinators. At optimal light intensity, pollinators begin foraging and stop activity at low light intensity. Malerbo-Souza et al (2021) reported *Trigona spinipes*, stingless bees as frequent and constant insects in chayote flowers between 8:00 and 13:00 hrs. Sharma et al (2019) found highest foraging activity of *Bombus haemorroidalis* and *Apis cerana* between 9:00-11:00 hrs. Mukerjee et al (2019) observed that pollinators were most active between 7:30 and 14:30 hrs. Rashmi et al (2014) observed the highest activity of chayote pollinators between 9:00-11:00 hrs followed by 7-9 hrs and 11-13 hrs, and very low activity between 17-18 hrs. Yunin et al (2019) observed stingless bee, *Heterotrigona itama*, and *Tetraponera laeviceps* visited both staminate and pistillate flowers, with peak visitation occurring between 8:30 and 10:30 hrs. Peak foraging time of *Halictus* sp. in Niger was observed at 12:00 hrs and *Ceratina* sp. in Mustard at 10:00 hrs (Navatha 2012).

The foraging speed shares an inverse relationship with the time spent per flower. The least amount of time spent was observed between 15:00-17:00 hrs (6.74 seconds/flower), followed by 12:00-14:00 hrs and 9:00-11:00 hrs (Table 5). Among the eight species included in the study, the lowest time spent per flower was observed for *Apis cerana* (3.97 sec/flower), followed by *Polybia* sp. which is at par with *P. canifex*, *B. haemorroidalis* and *P. Canadensis*. The interaction study showed that the least time spent was observed for *A. cerana* between 15:00-17:00 hrs (3.11 sec./flower), which was at par with *B. haemorroidalis* between 15:00-17:00 hrs (3.54 sec./flower). Thakur and Rana (2008) also found that bees spent the highest time during 9:00-10:00 hrs (11.83 seconds/flower), followed by 12:00-13:00 hrs. The longer time spent on the flower was also reported by Rana et al (2005). The abundance of pollen and nectar in freshly opened flowers could be the reason for the highest time per flower in the morning (Nepi et al 1996).

The foraging rate was observed highest during 15-17 hrs (10.83 flowers/minute), followed by 12:00-14:00 hrs and 9:00-11:00 hrs (Table 6). The highest number of flowers were visited by *Apis cerana* (11.94 flowers/minute), followed by

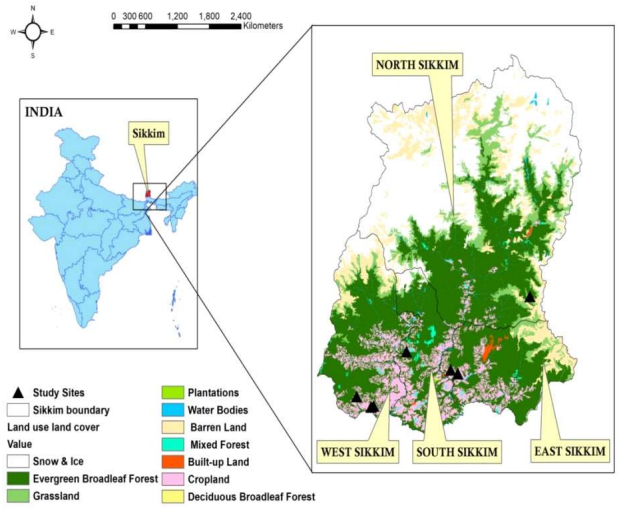

Fig. 1. Map depicting the study site

Table 1. Diversity of pollinators in chayote

Family	Common name	Scientific name	Species No.
Order Hymenoptera			
Apidae	Indian bee	*Apis cerana*	3
Apidae	Putka	*Lepidotrigona arcifera*	
Apidae	Bumble bee	*Bombus haemorroidalis*	
Halticidae	Sweat bee	*Lasioglossum aeneiventre*	1
Vespidae	Yellow paper	*Polistes carnifex*	5
Vespidae	Potter wasp	*Eumenes fraternus*	
Vespidae	Red paper wasp	*Polistes canadensis*	
Vespidae	Red and black mansion wasp	*Pachodynerus* sp.	
Vespidae	Social wasp	*Polybia* sp.	

Table 2. Insect visitor of chayote flower and their relative abundance

Family	Species	Total Species abundance (%)	Total family abundance (%)
Apidae	*Apis cerana*	17.83	37.60
	Lepidotrigona arcifera	10.47	
	Bombus haemorroidalis	9.30	
Halticidae	*Lasioglossum aeneiventre*	10.85	10.85
Vespidae	*Polistes carnifex*	13.57	51.54
	Eumenes fraternus	5.81	
	Polistes canadensis	13.95	
	Pachodynerus sp.	9.30	
	Polybia sp.	8.91	

Table 3. Diversity indices of insect pollinators of chayote

Diversity indices	
Shannon Index	2.131
Simpson Index	0.8741
Margalef	1.782
Berger-parker	0.191

Table 4. Temporal variation in pollinators relative abundance of chayote

Time (h)		9-11 hrs	12-13 hrs	14-15 hrs	Total
Relative abundance of pollinator	*Apis cerana*	15.79 (21)	17.39 (16)	27.27 (9)	17.83 (46)
	Lepidotrigona arcifera	9.77 (13)	10.87 (10)	12.12 (4)	10.47 (27)
	Bombus haemorroidalis	9.02 (12)	9.78 (9)	9.10 (3)	9.30 (24)
	Lasioglossum aeneiventre	12.03 (16)	10.87 (10)	6.06 (2)	10.85 (28)
	Polistes carnifex	13.53 (18)	13.04 (12)	15.15 (5)	13.57 (35)
	Eumenes fraternus	7.52 (10)	5.43 (5)	0.00 (0)	5.81 (15)
	Polistes canadensis	12.78 (17)	14.13 (13)	18.18 (6)	13.95 (36)
	Pachodynerus sp.	11.28 (15)	8.70 (8)	3.03 (1)	9.30 (24)
	Polybia sp.	8.27 (11)	9.78 (9)	9.09 (3)	8.91 (23)
	No of pollinator observed	133	92	33	258

Figure in the parenthesis are the number of insect observed

Table 5. Foraging speed of pollinators at different hours of the day (Sec/flower)

Pollinators	Time spent/flower (Sec)			Mean
	9:00-11:00 hrs	12:00-14:00 hrs	15:00-17:00 hrs	
A. cerana	4.50^{ijk}	4.32^{kl}	3.11^{m}	3.97^{e}
L. arcifera	15.07^{d}	13.12^{e}	9.45^{f}	12.55^{b}
B. haemorroidalis	5.28^{hi}	4.68^{ijk}	3.54^{lm}	4.50^{d}
Lasioglossum aeneiventre	29.23^{a}	25.06^{b}	20.66^{c}	24.98^{a}
P. carnifex	4.75^{ijk}	4.42^{ijk}	4.12^{ijk}	4.43^{dc}
Pachodynerus sp.	6.29^{g}	5.72^{gh}	4.82^{ijk}	5.61^{c}
P. Canadensis	5.21^{hij}	4.65^{ijk}	4.13^{kl}	4.66^{d}
Polybia sp.	4.60^{ijk}	4.34^{jkl}	4.12^{kl}	4.35^{dc}
Mean	9.37^{a}	8.29^{b}	6.74^{c}	
	Species	Day Hours	Species X Day Hours	
CD	0.51	0.31	0.88	
CV		9.45		

The same letter are statistically non-significant

Table 6. Pollinator foraging rate (flowers visited/min) at different hours of the day

Pollinators	Time spent/flower (Sec)			Mean
	9:00-11:00 hrs	12:00-14:00 hrs	15:00-17:00 hrs	
A. cerana	10.83	11.83	13.17	11.94^{a}
L. arcifera	1.22	1.55	2.18	1.65^{f}
B. haemorroidalis	8.50	9.66	11.53	9.90^{d}
Lasioglossum aeneiventre	0.97	1.22	1.78	1.32^{f}
P. carnifex	10.33	11.17	12.17	11.22^{b}
Pachodynerus sp.	7.00	8.50	10.17	8.56^{e}
P. Canadensis	9.83	10.33	12.00	10.72^{bc}
Polybia sp.	7.25	10.23	10.83	10.33^{cd}
Mean	9.33^{c}	10.23^{b}	10.83^{a}	
	Species	Day Hours	Species X Day Hours	
CD	0.70	0.43	NS	
CV		0.43		

The same letter are statistically non-significant

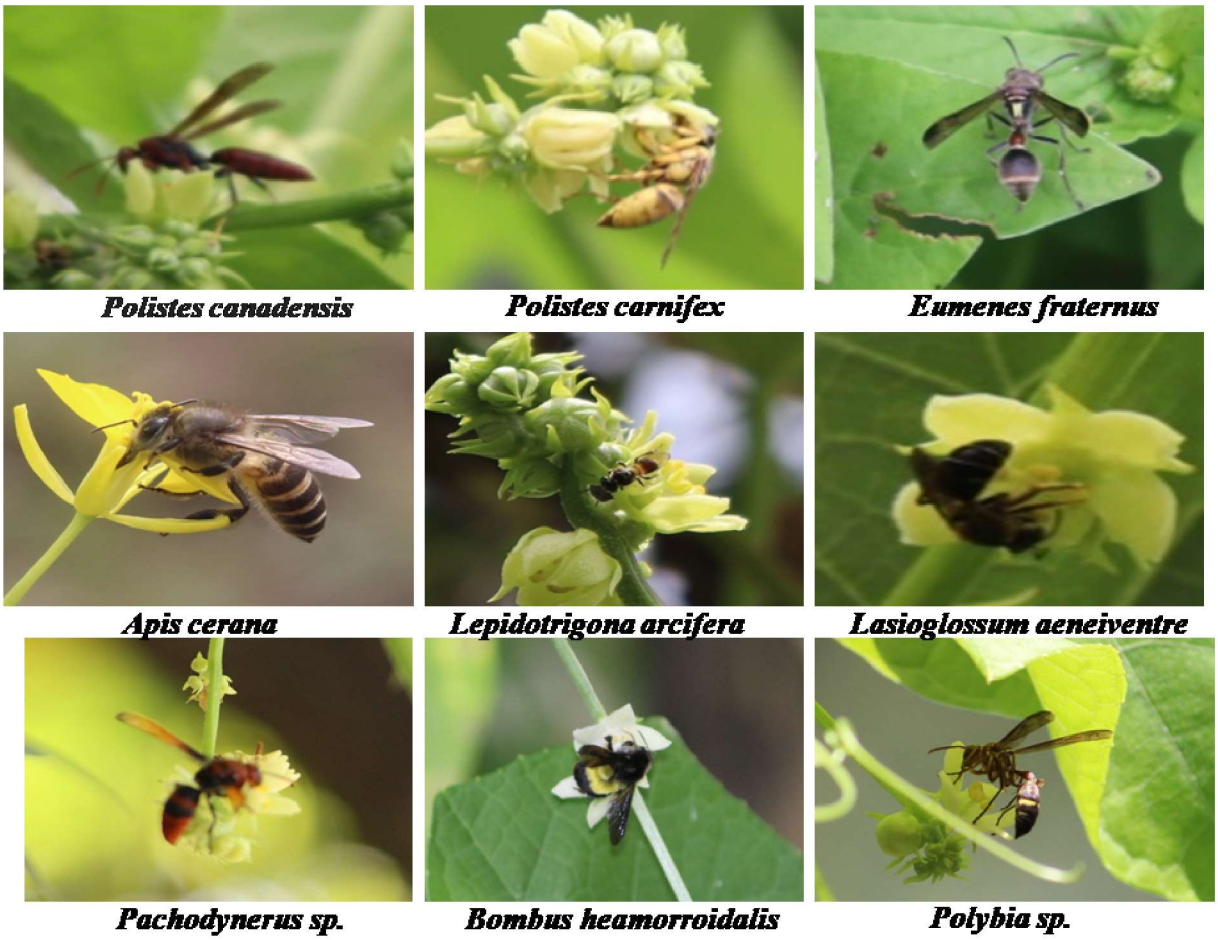

Fig. 2. Pollinators of chayote

Polistes carnifex which was at par with *P. canadensis* (10.72 flowers/minute) and the least flowers were visited by *Lasioglossum aeneiventre* which was at par with *L. arcifera*. Thakur and Rana (2008) observed the same pattern in the foraging rate. They found the highest foraging rate between 15:00-16:00 hrs (7.25 flowers/minute), followed by 12:00-13:00 hrs and 9:00-10:00 hrs. The reason for the high foraging rate in the afternoon followed by late afternoon could be due to insufficient nectar and pollen due to repeated visits. In the study of pollinators (*Apis cerana, Lasioglossum aeneiventre* and *Lepidotrigona arcifera*) of chayote some of the pollinators were also observed foraging in weeds such as *Ageratum conzoyoides* , *Ageratum houstonianum* , *Bidens pilosa*, *Persicara nepalensis*, *Solanum nigrum* , *Chenopdium album*, *Galingsoga parviflora* in Chayote area. Of the pollinators, *Apis cerana* was abundantly encountered foraging on *Bidens pilosa.*

CONCLUSIONS

Chayote production is in decreasing trend for the last observed decade in the eastern Himalayas of India due to diseases, pests, and other factors. Under these circumstances, a thorough study of pollinators is the need of the hour to recommend revival measures to increase the productivity of chayote. The present study has identified eight species of pollinators for Chayote, indicating high species richness in chayote. The foraging activities of pollinators were influenced by the time of the day. The highest pollinator activity was observed between 9:00 and 11:00 hrs. The honey bee (*Apis cerana*) was the most abundant pollinator of chayote but wasp species were more in number. Therefore, *Trigona* sp. has been reported as the most efficient pollinators of chayote. Further studies can be conducted to determine the efficiency level of pollinators of chayote.

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Biochemical Basis of Phytoimmunity in Cotton Genotypes against Leafhoppers

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***Abstract*:** The research was carried out at Haradanahalli Farm, Chamarajnagar, University of Agricultural Sciences, Bangalore, Karnataka during 2020-21 to understand role of biochemical constituents and minerals in plant resistance against leafhoppers in cotton. Fifteen cotton genotypes representing each resistant category from the results of field screening were analyzed for various biochemical and mineral constituents. Higher amount of phenols, tannins, phosphorus and potassium were observed in highly resistant genotypes and total soluble sugars, total reducing sugars, crude proteins, total free amino acids and nitrogen were higher in highly susceptible genotypes. Total phenols, tannins, phosphorus and potassium had significant negative relationship with incidence of leafhoppers while, total soluble and reducing sugars, total free amino acids, crude proteins and nitrogen had significant positive association with incidence of leafhoppers.

***Keywords*:** Genotypes, Resistant and Biochemical constituents

Cotton is the most important fiber crop in many regions of the world. Traditionally cotton is known as the backbone of non-food crops of agricultural economy of India (Sharma 2015). Many insect pests cause economic damage in cotton growing areas; among them sucking pests particularly leafhoppers are more threatening in present scenario (Makwana and Dulera 2018). Management through chemicals leads to many hazardous like environmental pollution, negative effects on existing flora and fauna and also leads to imbalance of tri-trophic interaction. Control of any pest to below its economic threshold level by single management practice is difficult. Integrated pest management is the best way to manage any pest population. Hence, identification of source of resistance in host plant is needful. In majority of the plants secondary metabolites and mineral constituents are involved in offering resistance against pest species. With this background, the study was formulated with an objective to study biochemical factors associated for resistance in cotton genotypes against leafhoppers'.

MATERIAL AND METHODS

Field screening of cotton genotypes: Total of 60 cotton genotypes were field screened against leafhopper during *Kharif* 2020. At All India Coordinated Research Project on cotton, Haradanahalli, Chamarajanagara. Each genotype was sown in replicated trial in 3 rows of 90 plants with spacing of 90 × 60 cm, between rows and plants, respectively. The plants of different genotypes were raised as per package of practice, except the plant protection measures (Anonymous 2016). In each genotype, the observations on nymphs and adults of leafhopper were recorded on 45 and 60 DAS on ten randomly selected plants. In each plant three leaves - one each from top, middle and bottom strata- were observed and mean population per three leaves was worked out. The hopper-burn assessment was rated by adopting 1-4 Grade Scale (Indian Central Cotton Committee). Based on LHRI (Leaf Hopper Resistance Index) the genotypes were categorized as highly resistant, resistant, intermediate, susceptible and highly susceptible with 1.0-1.5, 1.51-2.0,2.01-2.5, 2.51-3.0 and 3.01-4.0 (Rao 1973). The genotypes of cotton representing resistant category were selected for sampling The un-infested leaves of selected cotton genotypes were sampled at 60 days after sowing. The sampled genotypes were collected separately in a butter paper for the estimation of the important biochemicals *viz.,* the total and reducing sugars, total phenols, total free amino acids, tannins and crude proteins and major nutrients *viz.,* N, P, K were estimated. The leaf samples of selected genotypes were dried under shade for two weeks. The dried samples were ground using grinder. The powdered samples were stored in plastic covers until analysis.

Estimation of biochemical components: The leaf samples of selected cotton genotypes were collected, washed with

distilled water and dried under shade. 10 g of leaf sample was taken in separate conical flask and 150 m of 80 percent ethanol was added and refluxed for 30 minutes on hot water bath. After boiling, the extract was cooled and tissues were ground thoroughly in a mortar with pestle in slight ethanol. The supernatant was decanted in to another flask and residue were again re-extracted with small quantity of hot ethanol and decanted. This extract was filtered through Whatman's No.1 filter paper and made up to a known volume with 80 percent ethanol. The ethanol part of extract was stored in refrigerator at 4 ℃ and used for the estimation of biochemical components present in plant sample. The total and reducing sugars in each test genotypes were estimated by the method suggested by Somogyi. Estimation of total phenols and tannins in stem samples of test genotypes was done by following Folin-Ciocalteau method suggested by Bray and Thorpe (1954). The amount of total free amino acid present in the samples was estimated by Ninhydrin method. Nitrogen and crude proteins were estimated by micro-Kjeldahl method, phosphorous by spectrophotometric method and potassium by flame photometric method.

Statistical analysis: The mean data was processed after suitable transformation, using SPSS Software.

RESULTS AND DISCUSSION

Total phenols: The higher amount of phenol was recorded in cotton genotypes Br-24b 2671 and Br-24b 2675 and were on par with each other and lower amount of phenol content was in highly susceptible genotypes *viz.,* Br-2b 376, Br-2b 356 and Br-2b 373 (Table 1). The correlation study concluded that phenol content had significant negative correlation with leafhopper incidence (r=-0.91**) (Table 2). Higher leaf phenol content will lead to a lower leaf hopper injury index (Rohini et al 2011), which is generally determined by the smaller number of leafhopper population (Halder et al 2016, Raju et al 2020) owing to the phenols antibiosis nature in resistant cultivars.

Tannins: The amount of tannins increased as resistance increases. The highly resistant genotype has higher tannins in Br-24b 2671 and Br-24b 2675 and genotypes. Br-2b 376, Br-2b 356 and Br-2b 373recorded lower amount of tannins as they belongs to highly susceptible genotypes (Table 1). The tannins had significant negative association with leafhopper incidence (r=-0.90**) (Table 2). More tannins decrease leafhoppers (Sandhi et al 2017), due to tannin's significant contribution in conferring cotton's defence system against sucking insects (Nikhath et al 2019, Raju et al 2020).

Total free amino acids (TFA): Differences in TFA among genotypes were significant and showed an increasing trend with susceptibility and exhibited significant positive (r=0.76**) relationship with incidence of leafhopper (Table 2). Among the selected genotypes, highly resistant genotypes Br-24b 2671 and Br-24b 2675 recorded least amount of TFA**.** Lower amount of TFA was observed in CET H × B 20605 this followed by CET H × B 20609 and Br-13a 2668 (Table 1).

Crude proteins: Crude proteins were found lower in highly resistant genotypes *i.e.,* Br-24b 2671 and Br-24b 2675. However, the highest per cent crude proteins was observed in highly susceptible genotypes Br-2b 376, Br-2b 356 and Br-2b 353 and were found differed significantly (Table 1). The increasing trend of crude proteins was observed in cotton genotypes with increase susceptibility which was positively correlated with incidence (r= 0.85**) (Table 2). Elevated levels of proteins in the plant also favour the incidence of leafhoppers in cotton (Amin et al 2016, Manivannan et al 2021) which are built from amino acids and these amino acids are essential for the growth and development of insects (Manivannan et al 2021). Contrarily, a non-significant correlation between protein content and leafhopper infection in cotton genotypes was also found (Murugesan and Kavitha 2010).

Total soluble sugars (TSS): The total soluble sugars varied significantly and a lower amount of TSS was observed in highly resistant genotypes *viz*., Br-24b 2671 and Br-24b 2675. However, in highly susceptible genotypes the amount of TSS was found significantly highest in Br-2b 376, Br-2b 356 and Br-2b 353 were on par with each other. The increasing trend of TSS in different genotypes showed a significant positive impact on leafhopper incidence ($r=0.90^{**}$). However leafhoppers had negative non-significant association of total sugars on okra (Sandhi et al 2017) and on Bt cotton genotypes (Nikhath et al 2019).

Total reducing sugars (TRS): In different genotypes, total reducing sugar varied between 1.24 to 4.16 mg g^{-1}. The significant and lower amount of TRS was recorded in highly resistant categories *viz*., Br-24b 2671 and Br-24b 2675. However, in highly susceptible genotypes total reducing sugar varied between 4.00 and 4.16 mg g^{-1}(Table 2). TRS had positive significant influence (r= 0.88**) on leafhopper population (Table 2). Reducing sugars had positive and highly significant correlation between pest populations in *Bt* cotton genotypes (Nikhath et al 2019).

Nitrogen (N): The nitrogen content was low in highly resistant genotypes Br-24b 2675 and Br-24b 2671 were on par with each other. Higher amount of nitrogen content was quantified in highly susceptible genotypes. Correlation study revealed that percent nitrogen in leaf sample exerted significant positive influence on incidence of leafhopper (r=0.87**) (Table 2). Higher N content makes leaves more succulent, which supports more sucking pests (Sonalkar,

2019). N is also a key component of amino acids, which promotes higher population of leafhoppers.

Phosphorus (P): Highly resistant genotypes Br-24b 2671 and Br-24b 2675 had higher amount (0.36%) of phosphorus and were on par with each other. In highly susceptible genotypes Br- 2b 376, Br-2b 356 and Br-2b 353 were on par

Table 1. Biochemical constituents in cotton genotypes in relation to leafhopper incidence, *Kharif* 2020

Genotypes	LHRI	Category	Incidence (No./3 leaves)	Total phenols	Tannins	TFA	Crude proteins	TSS	TRS	N (%)	P (%)	K (%)
Br-24b 2671	1.00	HR	0.00 (0.71)	6.37^{a}	7.96^{a}	1.24^{a}	12.83^{a}	8.28^{a}	1.24^{a}	0.22 (2.66)^{a}	0.36 (3.45)^{a}	1.68 (7.44)^{a}
Br-24b2675	1.00		0.00 (0.71)	6.35^{a}	7.86^{a}	1.25^{a}	12.75^{a}	8.32^{ab}	1.35^{b}	0.21 (2.65)^{a}	0.36 (3.45)^{a}	1.68 (7.44)^{a}
Br-24b 2672	1.60	R	1.67 (1.47)	6.05^{bc}	7.38^{b}	1.36^{a}	13.98^{ab}	8.63^{b}	2.63^{ef}	0.24 (2.78)^{ab}	0.35 (3.37)^{ab}	1.63 (7.34)^{b}
Br-24b 2673	1.80		2.57 (1.75)	5.95^{bcd}	7.28^{b}	1.37^{a}	15.09^{bc}	8.51^{ab}	1.52^{c}	0.25 (2.89)^{bc}	0.35 (3.38)^{ab}	1.62 (7.31)^{b}
Br-24b 2676	2.00		2.23 (1.65)	6.08^{b}	7.47^{b}	1.36^{a}	13.82^{ab}	8.31^{ab}	1.31^{ab}	0.23 (2.76)^{b}	0.34 (3.36)^{abc}	1.58 (1.58)^{c}
CET H × B 20601	2.20	I	4.33 (2.20)	5.89^{bcd}	6.63^{c}	1.36^{a}	15.63^{bc}	9.56^{c}	2.56^{e}	0.26 (2.94)^{bc}	0.32 (3.27)^{bcd}	1.48 (6.99)^{d}
CET H × B 20605	2.20		5.53 (2.46)	5.84^{cde}	6.66^{c}	2.28^{c}	16.36^{c}	9.68^{c}	2.68^{f}	0.28 (3.01)^{cd}	0.31 (3.21)^{d}	1.46 (6.94)^{de}
CET H × B 20606	2.40		5.20 (2.39)	5.64^{e}	6.61^{c}	1.35^{c}	15.59^{bc}	12.64^{f}	3.66^{i}	0.26 (2.93)^{bc}	0.24 (2.82)^{f}	1.47 (6.97)^{de}
CET H × B 20609	2.40		5.57 (2.46)	5.78^{de}	6.58^{c}	2.29^{c}	16.54^{cd}	11.46^{d}	2.46^{df}	0.28 (3.02)^{cd}	0.23 (2.78)^{f}	1.47 (6.96)^{de}
CET H × B 20610	2.40		6.47 (2.64)	5.76^{e}	6.54^{c}	2.37^{c}	16.96^{cd}	11.60^{d}	2.61^{e}	0.29 (3.06)^{cd}	0.32 (3.26)^{cd}	1.45 (6.92)^{e}
Br-13a 2661	2.60	S	9.53 (3.17)	4.88^{f}	5.86^{d}	1.89^{b}	18.53^{d}	12.25^{e}	3.27^{h}	0.31 \(3.20)^{d}	0.27 (2.97)^{e}	1.36 (6.69)^{f}
Br-13a 2668	2.80		10.20 (3.27)	4.97^{f}	5.94^{d}	2.34^{c}	20.88^{e}	12.13^{e}	3.03^{g}	0.35 3.40)^{e}	0.29 (3.07)^{e}	1.36 (6.69)^{f}
Br-2b 376	3.40	HS	11.20 (3.42)	4.09^{h}	3.39^{e}	2.46^{c}	31.12^{f}	13.17^{g}	4.16^{k}	0.52 (4.15)^{f}	0.31 (3.20)^{d}	1.33 (6.62)^{f}
Br-2b 356	3.80		14.37 (3.86)	4.21^{gh}	3.37^{e}	1.86^{b}	32.43^{f}	13.07^{g}	4.07^{j}	0.55 (4.23)^{f}	0.22 (2.72)^{f}	1.24 (6.39)^{g}
Br-2b 373	3.60		15.30 (3.97)	4.40^{g}	3.33^{e}	2.46^{c}	32.96^{f}	13.01^{g}	4.00^{j}	0.55 (4.27)^{f}	0.32 (3.24)^{d}	1.22 (6.34)^{g}
SE m ±			0.021	0.048	0.037	0.035	0.403	0.067	0.018	0.036	0.023	0.013
CD@ p=0.05			0.061	0.138	0.107	0.101	1.168	0.195	0.053	0.106	0.067	0.038

Values in the column followed by common letters are non-significant at p=0.05 as per Tukey's HSD (Tukey, 1965); N- Nitrogen; P- Phosphorous; K- Potassium; *Values in the parenthesis are square root transformed (√x+0.5) in incidence and **Arc sign transformed in minerals; LHRI- Leaf Hopper Resistance Index (Rao 1973)

Table 2. Correlation matrix between biochemical constituent, minerals and leafhopper incidence, *Kharif* 2020

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Y-Leafhopper	-0.91**	-0.90**	0.76**	0.85**	0.90**	0.88**	0.87**	-0.62*	-0.86**
X_1- Phenols	1.00	0.96	-0.64	-0.94	-0.86	-0.87	-0.95	0.51	0.83
X_2-Tannin		1.00	-0.65	-0.98	-0.83	-0.87	-0.99	0.46	0.89
X_3- TFA			1.00	-0.62	0.70	0.59	0.65	-0.35	-0.60
X_4-Crude protein				1.00	0.77	0.81	0.99	-0.39	-0.84
X_5-TSS					1.00	0.91	0.79	-0.73	-0.80
X_6-TRS						1.00	0.82	-0.63	-0.83
X_7- Nitrogen							1.00	0.56	0.78
X_8-Phosphorus								1.00	0.79
X_9- Potassium									1.00

N = 15; ** Significant at P ≤ 0.01; TSS- Total soluble sugars; TRS- Total reducing sugars; TFA- Total free amino acids

with each other except Br-2b 356 which records lowest (0.22%) amount of phosphorus percent. The phosphorus showed significant positive association (r=-0.62*) with leafhopper incidence (Table 2).

Potassium (K): Decreased trend of potassium was observed as susceptibility increases. Among the selected genotypes higher amount of potassium was observed in highly resistant genotypes Br-24b 2671 and Br-24b 2675 and were on par with each other. The lowest amount of potassium was found in highly susceptible genotype Br-2b 353 followed by Br-2b 356 and Br-2b 376 (Table 1), potassium had significant negative relation with leafhopper incidence (r=-0.86**) (Table 2). Since potassium gives strong resistance to insect pests and high potassium levels increase secondary metabolite compounds, minimising carbohydrate deposition(Kiran et al 2018), potassium showed a negative non-significant link with leafhopper infestation on brinjal (Ali et al 2013). Increased K concentration in soil and rice plant lengthens the time it takes for Nilaparvata lugens to harm plant cells because K increases host plant tolerance (Rashid et al 2016).

CONCLUSION

In the present investigation, tannins, total phenols, phosphorus and potassium contents were higher in highly resistant and resistant genotypes but, crude proteins, total free amino acids, nitrogen, total reducing and soluble sugars were found higher quantity in highly susceptible and susceptible genotypes so, these components may acting as a key factors in phytoimmunity against leafhoppers in cotton.

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Abundance of Rose Pests in Relation to Major Abiotic Factors

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***Abstract*:** Abundance of rose pests in relation to abiotic factors was carried out at farmers field of Malotha, Tapi, Gujarat, India during 2018-2020. Highest thrips were observed during 18 and 17th SMW, respectively. Aphid attained peak during 3rd SMW while scale insect attained peak at 23rd SMW. Castor semilooper peaked at 37th SMW. Tussock moth attained peak during 46-47th SMW. Bud borer attained peak at 8th SMW. Thrips population on rose leaves and flowers exhibited highly significant and positive correlation with T_{max} while it was highly significant but negative with RH and rainfall. Aphid population exhibited highly significant but negative correlation with $T_{min.}$, RH and rainfall. Scale insect indicated highly significant and positive correlation with T_{max} and T_{min}. Castor semilooper exhibited highly significant and positive correlation with T_{min}, RH and rainfall while, it was significant but negative with T_{max}. Tussock moth exhibited significant positive correlation with RH and significant negative with T_{max}. The bud borer population indicated highly significant but negative correlation with T_{min}, RH and rainfall.

***Keywords*:** Seasonal abundance, Thrips, Aphid, Castor semilooper, Tussock moth and bud borer

Rose belong to the family Rosaceae and is one of the most important ornamental flower species used in landscape and cut flowers. In the international flower market, rose is ranked first among the top three cut flowers *viz*; rose, chrysanthemum and carnation (Hegde 2010). The estimated area under rose cultivation and its cut flower production was 29.57('000) hectares and 172.294 ('00000) MT, respectively (Anonymous 2016-2017). Area and production of rose in Gujarat is 4161 ha with 39049 MT production, respectively (Director Agriculture and Horticulture 2019-2020). Among the various factors affecting production and quality of flowers, pests and diseases are of prime importance. The most commonly associated pests on rose are *viz*; thrips, *Frankliniella schultzei* (Pergande), *Scirtothrips dorsalis* Hood (Thysanoptera : Thripidae); aphid, *Macrosiphum rosae* (Linnaeus) (Hemiptera: Aphididae); whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae); mealybug, *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae); foliage feeders and bud borers, *Helicoverpa armigera* (Hubner)(Lepidoptera: Noctuidae); *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) and mite, *Tetranychus urticae* Koch (Acarina: Tetranychidae) (Dreistadt 2001, Rajkumar et al 2004). About sixteen species of insects and one species of mite were observed as pest and associated with various stages of the rose crop (Reddy 2018). As not much information is available on abundance of pests on rose in relation to weather factors, this experiment was carried out under open field condition from 2018 to 2020.

MATERIAL AND METHODS

The study based on seasonal abundance of rose pests was carried out under open field condition (plot size 400 m^2) at farmers field (latitude: 21.044694, longitude: 73.377468) of village Malotha, taluka Vyara, district Tapi in the Gujarat state of India during 2018-2020 on rose cv. Gladiator. Fertilizer application was done as per the recommendation. All the other cultural operations including irrigation was followed as and when required.

Method of recording observation: The regular plot under rose cultivation was selected and observations were recorded at standard week wise interval on 50 plants selected randomly. The observations on pest count were made during two years (2018-20) on each rose plant. The data of two years was summarized and pooled results are mentioned hereunder:

Thrips: Thrips were counted on randomly selected plants by tapping leaves and flowers on black paper. Thus, pest population per leaf and flower was assessed (Duraimurugan and Jagadish 2004).

Aphid: Nymph and adult aphids were counted on the plants by selecting three tender shoots of 10 cm length (Hole et al 1997). The pest population for one shoot per plant was computed.

Foliage feeders and bud borers: Number of larvae of castor semilooper, tussock moth and bud borer were counted on selected plants. The plants were examined thoroughly and absolute population of larvae was recorded at standard

week wise interval (Patel and Koshiya 1997). The pest population per plant was computed.

Meteorological parameters: For developing insect pest management programme for specific agro-ecosystems, information on abundance and distribution of pest in relation to weather parameters *viz*; temperature (maximum, minimum), relative humidity, rainfall, rainy days and sunshine were procured daily during the experimental period and later computed at standard week wise interval.

Statistical analysis: Relationship between pest population and weather parameters were studied using correlation and regression using SPSS software.

RESULTS AND DISCUSSION

The pooled results of both the years (2018-2020) are presented and discussed in Table 1-3.

Thrips: Highest population of thrips was during 17th and 18th and SMWs, respectively (Table 1). The correlation studies of both the years indicated highly significant and positive correlation of thrips population on rose leaves with maximum temperature (T_{max}) while, it was highly significant but negative with RH and rainfall. Likewise, thrips population on rose flowers were highly significant and positively correlated with T_{max} while, it remained highly significant but negative with RH and rainfall (Table 2). Total contribution of all the weather factors on abundance of thrips on rose leaves was 83.3 per cent indicating significant multiple correlation. Likewise, total contribution of all the weather factors on abundance of thrips on rose flowers was 75.1 per cent indicating highly significant multiple correlation (Table 3). Relationship of thrips population with maximum temperature was significant and positive implying that with increase in temperature, there was bound to rise in the thrips on rose leaves and flower and vice-versa. Patel (2006) indicated appearance of thrips on rose flowers throughout the year except in rainy season at 23rd SMW (1st week of June) wherein thrips population was reported to have positive correlation with maximum temperatures, while it exhibited negative correlation with relative humidity which confirms the present findings wherein same trend of thrips population on leaves and flowers was also reported. Hegde (2010) reported thrips abundance throughout the flowering period which attained peak during May. Bukero et al (2015) found maximum thrips population at 14th SMW (2nd April) wherein the pest population was negatively correlated with temperature and relative humidity. Similarly, Norboo et al (2017a) observed in 14th SMW which reached its peak at 48th SMW. In the present findings, the thrips population remained highest during warmer days (17-18 SMW) indicating significant positive correlation with maximum temperature. So, the present findings are more or less same as reported earlier and some variation reported earlier might be due to variation in ecological conditions of present investigation and earlier reports. This implies that with unit increase in temperature and unit decrease in RH and rainfall there was corresponding increase in thrips population on rose plant under open field conditions and vice-versa.

Aphid: Aphid population was observed on rose from 50th SMW and reached to its peak at 3rd SMW. Thereafter, the pest population was found declining. No variable could exhibit positive relationship with aphid population however, it indicated highly significant but negative correlation with minimum temperature) $T_{min.}$, RH and rainfall . Negative impact of weather parameters on aphid population implied that unit decrease in these variables led to increase in aphid numbers and vice-versa. Total impact of all-weather factors considered in this investigation on aphid abundance was 67.4 per cent with highly significant multiple correlation coefficient (Table 3). Kmiec (2007) studied different groups of rose in relation to first occurrence of *Macrosiphum rosae* aphids in April and colonies in December. Mehrparvar *et al.* (2008) reported two peaks of rose aphid in a year (May and December). Hegde (2010) found peak aphid density during August indicating positive correlation with maximum relative humidity and negative correlation with maximum temperature. Quratulain et al (2015) observed development of aphid population in November and another rise at the end of February. The present findings are similar to this report wherein the aphid population peaked in colder months; however, the findings tend to vary from other the reports which could be due to difference in location and ago-ecological conditions. This implies that with unit decrease in temperature, relative humidity and rainfall there was corresponding increase in aphid population on rose buds and vice-versa.

Scale insect: The buildup of scale insect on rose started from 17th SMW which later attained peak status at 23rd SMW. Highly significant and positive correlation was found to exist between scale insect and T_{max} and T_{min}. The multiple correlation coefficient explained variation to the tune of 70.6 per cent due to all the weather factors taken into consideration. Hegde (2010) found infestation of red scale and soft scale on rose from January to June wherein pest attained peak during April- May. In the current investigation also peak population of scale insect was observed on rose during 23rd SMW. This indicate that with unit increase in these variables there was corresponding increase in larval population of the semilooper and vice-versa.

Castor semilooper, *A. janata*: Larval population of castor semilooper started appearing from 25th SMW. The pest

Table 1. Abundance of major pests of rose at farmers field (Malotha, Vyara, Tapi, Gujarat, India) during (2018-19 to 2019-20)

SMW	Thrips/ leaf	Thrips/ flower	Aphids /bud	Scales /shoot	Semilooper larva/plant	Tussock moth larva/plant	Bud borer larva/plant
15	2.23	6.97	0.00	0.00	0.00	0.00	0.09
16	2.14	6.91	0.00	0.00	0.00	0.00	0.04
17	2.48	7.30	0.00	3.66	0.00	0.00	0.00
18	2.56	6.84	0.00	3.86	0.00	0.00	0.00
19	2.23	6.29	0.00	9.54	0.00	0.00	0.00
20	1.90	5.47	0.00	9.80	0.00	0.00	0.00
21	1.78	5.28	0.00	11.54	0.00	0.00	0.00
22	1.59	4.16	0.00	13.32	0.00	0.00	0.00
23	1.42	3.76	0.00	16.71	0.00	0.00	0.00
24	1.41	3.96	0.00	13.24	0.00	0.00	0.04
25	1.37	3.61	0.00	15.84	0.09	0.00	0.05
26	0.95	2.57	0.00	15.40	0.08	0.00	0.00
27	0.71	2.26	0.00	13.39	0.12	0.00	0.00
28	0.78	2.24	0.00	5.88	0.14	0.00	0.00
29	0.75	2.12	0.00	3.84	0.16	0.00	0.00
30	0.78	1.90	0.00	1.07	0.19	0.00	0.00
31	0.58	1.15	0.00	0.00	0.26	0.00	0.00
32	0.57	1.83	0.00	0.00	0.45	0.06	0.00
33	0.59	1.88	0.00	0.00	0.26	0.09	0.00
34	0.60	2.02	0.00	0.00	0.25	0.12	0.00
35	0.61	2.26	0.00	0.00	0.23	0.16	0.00
36	0.61	2.41	0.00	0.00	0.27	0.19	0.00
37	0.85	2.47	0.00	0.00	0.49	0.19	0.12
38	0.92	3.11	0.00	0.00	0.37	0.15	0.09
39	1.02	3.30	0.00	0.00	0.29	0.16	0.06
40	1.14	3.42	0.00	0.00	0.33	0.12	0.00
41	1.18	3.82	0.00	0.00	0.22	0.20	0.08
42	1.23	4.30	0.00	0.00	0.14	0.19	0.26
43	1.36	5.12	0.00	0.00	0.14	0.18	0.40
44	1.50	6.15	0.00	0.00	0.18	0.22	0.36
45	0.78	2.10	0.00	0.00	0.31	0.19	0.00
46	1.00	2.52	0.00	0.00	0.23	0.26	0.00
47	1.03	2.26	0.00	0.00	0.16	0.26	0.07
48	0.97	1.94	0.00	0.00	0.00	0.22	0.15
49	0.42	0.18	0.00	0.00	0.00	0.05	0.10
50	0.41	0.41	1.74	0.00	0.00	0.05	0.07
51	0.63	0.84	3.86	0.00	0.00	0.00	0.10
52	0.72	1.32	5.76	0.00	0.00	0.00	0.07
1	0.71	2.10	6.10	0.00	0.00	0.00	0.00
2	0.98	2.05	8.76	0.00	0.00	0.00	0.17
3	1.16	2.60	10.55	0.00	0.00	0.00	0.24
4	1.20	3.13	8.68	0.00	0.00	0.00	0.34
5	0.97	3.54	9.16	0.00	0.00	0.00	0.36
6	1.36	4.78	7.50	0.00	0.00	0.00	0.37
7	1.63	4.61	5.47	0.00	0.00	0.00	0.40
8	1.62	4.67	3.31	0.00	0.00	0.00	0.50
9	1.84	5.12	1.51	0.00	0.00	0.00	0.39
10	1.92	4.93	1.09	0.00	0.00	0.00	0.38
11	1.94	4.85	0.00	0.00	0.00	0.00	0.35
12	1.73	4.11	0.00	0.00	0.00	0.00	0.44
Mean	1.22	3.46	1.47	2.74	0.11	0.06	0.12

Table 2. Correlation coefficients of rose pests in relation to weather parameters (2018-19 to 2019-20)

Parameters	Correlation coefficients						
	Thrips/ leaf	Thrips/ flower	Aphids /bud	Scales /shoot	Semilooper larva/plant	Tussock moth larva/plant	Bud borer larva/plant
$T_{max.}$ (°C)	0.880**	0.802**	-0.269	0.397**	-0.500**	-0.280*	0.005
$T_{min.}$ (°C)	0.171	0.237	-0.795**	0.598**	0.352*	0.046	-0.569**
RH (%)	-0.576**	-0.446**	-0.512**	0.150	0.775**	0.347*	-0.543**
Rainfall (mm/day)	-0.449**	-0.378**	-0.292*	0.243	0.423**	-0.072	-0.384**

*Significant (p = 0.05) **Significant (p = 0.01)

Table 3. Regression coefficients of rose pests in relation to weather parameters (2018-19 to 2019-20)

Parameters	Correlation coefficients						
	Thrips/ leaf	Thrips/ flower	Aphids /bud	Scales /shoot	Semilooper larva/plant	Tussock moth larva/plant	Bud borer larva/plant
Constant	-2.656	-7.467	26.180	31.925	-0.392	-0.786	1.984
$T_{max.}$ (°C)	-0.140	-1.144	0.077	3.665	-0.098	-0.001	-0.154
$T_{min.}$ (°C)	-0.361	-1.865	0.703	9.258	-0.150	-0.071	-0.084
RH (%)	0.003	0.019	-0.141	-0.570	0.011	0.011	-0.013
Rainfall (mm/day)	0.006	-0.006	0.056	0.129	-0.007	-0.008	-0.003
Multiple correlation (R)	0.913	0.867	0.821	0.840	0.889	0.706	0.691
Total variation explained (%)	83.3	75.1	67.4	70.6	88.9	49.8	69.1

multiplied further indicating peak at 37th SMW. Highly significant and positive correlation of semilooper population was reported with T_{min}, RH and rainfall while, it indicated significant but negative correlation with $T_{max.}$ The multiple correlation coefficient explained 88.9 per cent variation due to all the weather factors. Positive correlation between larval population of semilooper with minimum temperature, RH and rainfall indicate that with increase in every unit of these parameters there was corresponding increase in pest population and vice-versa while, maximum temperature had negative relationship with the pest build up implying increase in pest led to decrease its population. The unit increase in RH and unit decrease in maximum temperature will increase larval population of tussock moth and vice-versa.

Tussock moth, *Orgyia* sp.: Larval population of tussock moth started appearing from 32nd SMW attaining peak during 46-47th SMWs thereafter, the population declined gradually. Population of the tussock moth exhibited significant positive correlation with RH while, it indicated significant negative correlation with T_{max} (Table 2). Multiple correlation coefficient explained 49.8 per cent variation due to all the weather factors (Table 3). Thus, it is evident from the above results that larval population of tussock moth increased with unit increase in relative humidity and decrease in maximum temperature.

Bud borer, *H. armigera*: The bud borer *H. armigera* population started appearing from 15th SMW indicating highest larval population at 8th SMW. Bud borer population failed to establish positive relationship with any variable considered in this investigation. However, it indicated significant but negative correlation with $T_{min.}$ RH and rainfall. Multiple correlation coefficient explained 69.1 per cent due to all the weather factors taken into consideration. Hegde (2010) reported occurrence of *H. armigera* larvae throughout the year indicating higher density from August to October wherein varied from 0.5 to 2.2 per plant. In the present findings, larval population of *H. armigera* varied inconsistently throughout the year wherein the active period of the pest was reported during 42nd-44th SMWs which is also reported in the above report. Thus, the current results are more or less in accordance with the earlier reports. The with unit decrease in the above abiotic factors there was corresponding increase in larval population of bud borer under open field condition.

CONCLUSION

Peak activity of thrips was observed during 17th-19th SMW while, scale insects remained very active during 23rd SMW. Aphid and bud borer *H. armigera* indicated higher activity during 3rd-8th SMW. Castor semilooper and Tussock moth remained very active during 46-47th SMW. Thrips population was influenced positively by temperature and negatively by

RH and rainfall. Aphid was influenced negatively by temperature, RH and rainfall. Scale insect and castor semilooper were directly influenced by temperature while tussock moth was directly associated with RH and indirectly with maximum temperature. Bud borer, *H. armigera* was negatively influenced by temperature, RH and rainfall.

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Development of Forecasting Model for Assessing Disease Risk and Non-Risk Period in Fusarium Wilt X Banana Pathosystem

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***Abstract*:** Fusarium wilt caused by fungi *Fusarium oxysporum* f. sp. *cubense*, is one of the major production constraints of banana. The pathogen is soil-borne and produces chlamydospores responsible for its prolonged perpetuation in the soil. Banana being under perennial plantation, suffers a lot from this disease if, sufficient primary inoculum presents in the soil. Along with it, soil temperature (ST) and soil moisture (SM) have great influence in the epidemiology of this disease. The objective of this study is to develop a suitable forecasting model for its future use in computer simulation to predict the epidemic by feeding ST and SM data. The experiment was conducted with G9 variety of banana planted in Fusarium wilt endemic area for three consecutive years (2019-2021). With the initiation of the disease, SM and ST data was collected at a regular interval of 10 days and its corresponded effect on disease incidence was recorded. The model developed was Y'= -85.30 + 2.556 SM + 3.732 ST. The result showed both the factors have positive significant effect on disease progression. Among them, SM was more influential though the combination 60-65% SM and ST 30-35^{0}C played major role in disease establishment. Discriminant analysis unveiled, for each additional unit increase in SM and ST will increase the likelihood of being in disease risk group by 0.26 and 0.19 respectively that could be used for predictive purpose. The correctness of the model was determined with 72.3 % accuracy.

Keywords: AUDPC, Banana, Fusarium wilt, Disease modelling, Model evaluation

Banana (*Musa* spp.) holds a prominent position in the major food list being the fifth most economically valued agricultural food product (Hossain et al 2016). Among Asian nations, India stands as a preeminent producer of bananas, accounting approximately 25.7% of the global output (FAO 2021). Banana is highly nutritious and easily digestible and rich in potassium and calcium but low in sodium (Wall 2006). In Indian context, the nation contributes to annual production of 30.86 million tonnes of bananas in approximate 860,000 hectares, constituting around 21% of the global area (Thangavelu et al 2020, Musapedia 2021). Despite considerable research efforts dedicated to comprehending various aspects of the disease, substantial economic losses continue. Estimated yearly losses of banana by *Fusarium oxysporum* f. sp. *cubense* (Foc) in the world ranging from 60 to 90% including India (Bhuvanendra et al 2010). However, among the formidable challenges offered by biotic stresses, Foc gets the competitive advantages over the other pathogens by being majorly saprophytic (facultative parasite), having 4 different races, more than 20 vegetative compatibility groups and production of chlamydospores that can survive in the soil for more than 20 years (Niwas et al 2022). The pathogen penetrates the roots and spreads gradually till it reached the centre of the corm. After that, the plants produce characteristic symptom “quick wilting”. Purplish darker discoloration shows up in the xylem and get blocked. External leaves and pseudo-stem turn yellow and finally hang down. With the prevailing of conducive environments like soil temperature (25-30^{0}C) along with soil moisture (0.10 to 0.17 cm^3/cm^3) the symptoms become evident within 5-6 months of planting. The issue has been exacerbated by the prolonged monoculture of bananas (Perrier et al 2011), that is known escalate the incidence of Foc and consequently led to reduced crop yield with quality compromised (Shen et al 2017).

It is still challenging to manage the disease due to limited availability of the chemicals. Moreover, hazardous impact of chemicals in the environment through reiterate application should be equally counted (Panth et al 2020). To develop sustainable management practices crop rotation, biological control, use of resistant varieties and botanicals have been employed extensively but still the pathogen is proliferating all the year round and threatening the ecosystem (Rahman et al 2021). Hence, effort directed to find out the basis of survival advantage of Foc in soil under specific SM and ST combination and therefore, to determine the disease risk period. A predicting model will be developed to forewarn the stakeholders as well as to build up a holistic approach for sustainable and eco-friendly management of this disease.

MATERIAL AND METHODS

Study site and experimental layout: The experiment was conducted for three consecutive years (2019-2021) with banana cultivar G9 that was planted employing the heap method at a spacing of 1.8m X 1.8m, adhering to all recommended agronomic protocols. The experiment was laid out at the, College of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, West Bengal (Lat: 23.31^{0}N, Long: 87^{0}66' E and altitude: 36 m msl). The soil of the farm was clay loam in texture and belongs to the hyperthermic family with a pH of 7.3. No chemical was sprayed, and natural epiphytotic conditions were allowed for the disease establishment.

Disease scoring: Disease severity or percent disease index (PDI) was worked out to access the extent of damage caused by the disease using 0-9 scale (Mayee and Datar 1986). Details of the scale are: 0= no symptoms; 1=A few tiny necrotic patches that cover 1% or less of the leaf area; 3= A few tiny necrotic patches covering 1-5% of the leaf surface; 5= Coalescing spots expanding 6-20% of leaf area; 7= Spots grow in size and coalesce to reach 21-50% of the compound leaf area; 9= Spots expanding and merging to encompass at least 51% of the leaf area.

The percent disease index (PDI) was calculated McKinney (1923)

$$\text{PDI} = \frac{\sum[\text{No of leaves/scale} \times \text{scale value}]}{\text{Total number of observation} \times \text{highest scale}} \times 100$$

The values obtained from the above formula to evaluate disease severity were utilized to determine area under the disease progress curve (AUDPC) to quantify the disease over the period of time by Campbell and Madden (1990):

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{Yi + Yi+1}{2}\right)(t_{i+1} - t_i)$$

where, Yi = proportion of disease at the i^{th}observation, *ti* = time in days at the i^{th} observation and n = total number of observations

Soil temperature measured using soil thermometer (Maxtech white pen-type soil thermometer Model name/ Number: DT-9)

Soil moisture data recorded using a moisture meter (Lutron digital soil moisture meter, Model name/ Number: PMS 714).

(Data collected every day in the morning hours and average of 10 days was considered)

Construction of mathematical models: Binary logistic analysis and discriminant analysis (Tabachnink and Fidell 1996) was done in the stepwise method for disease risk and non-risk period (1/0) as the dependent variable and soil moisture (SM) and, soil temperature (ST) as independent variables.

Binary logistic regression: This special type of regression designed for modeling a categorical dependent variable.

$$\text{Logit}(p) = b_o + b_1x_1 + b_2x_2 \ldots\ldots\ldots\ldots + b_kx_k$$

$$\text{Logit}(p) = \ln[p/1-p]$$

$$p = 1/1 + e^{-\text{logit}(p)}$$

Where p is the probability of the event i.e disease risk (1) and non-risk (0).

Odds = p/(1-p) [p = presence of the event, (1-p) = 0 i.e., non risk.

$$\text{Odds} = p/1-p = e^{bi}X\, e^{b_1 x_1}Xe^{b_2 x_2}Xe^{b_3 x_3}X \ldots\ldots\ldots\ldots Xe^{b_k x_k}$$

This means when a variable Xi increases by 1 unit, with all other factors remaining unchanged, then the odds will increase by factor e^{bi}

Discriminant analysis: This linear regression interprets the output differently. Dependent variable is an indicator variable expressed as

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \ldots\ldots \beta_kx_k + e$$

y= 1 if the observation falls within the group i.e., disease risk

y = 0 if it doesn't. (Here, it is no risk for the disease).

Data analysis: Data on ST and SM were computed and their effect on FWB was analysed through MS Excel and the level of significance and interaction effects were evaluated. The value of percent disease incidence was subjected to arcsine (Gomez and Gomez 1984). Binary linear regression and discriminant analysis was performed through Minitab statistical software (Minitab LLC, USA).

Mathematical equations developed by using logistic binary regression and additionally by discriminant analysis to assess the model both quantitatively and dynamically. Finally, the accuracy of the model was evaluated, and fitness was appraised to epitomize the real aspect of the banana X fusarium pathosystem.

RESULTS AND DISCUSSION

Set up of binary logistic regression equation and development of prediction model: Data was recorded on disease severity and correspondent SM and ST. Disease condition below 20% considered as disease no risk and above that considered as disease risk period. For developing binary logistic regression three years collective data were used to access the impact of ST and SM (independent variable) on the disease severity (dependent variable) of FWB. This is a special type of logistic regression equation used to prepare the model on categorical dependent variable within the probability (p) either 0 or 1 where, (p) stands for probability of the event assumed as disease risk (1) and non-risk (0). Both the predictors (SM and ST) confer statistically significant contribution to predict the disease severity of FWB as confirmed (Table1). The odd ratio of ST (1.08) designates

every 1 unit increase in ST may cause rise in disease risk nearly 8%, whereas coefficient value of 2.43 and the odd ratio of 3.17 specifies SM tends to produce a higher disease risk of 3.17 times more in combination with ST when other factors remain unchanged in the model.

VIF (various implies factor) shows the correlation among the predictors (multicollinearity). VIF value 1.24 signifies SM and ST are moderately correlated in this model (Table 1). The goodness of fit displayed a high p-value ranging from 0.594 to 0.923 direct that model developed is good to accept (Table 2).

The model developed for fusarium wilt in banana under West Bengal, India condition using Binary logistic regression is as follows:

$P(1) = \exp(Y')/(1 + \exp(Y')$

$Y' = -85.3 + 2.556\ SM + 3.732\ ST\ [R^2 = 0.623\ R^2_{adj} = 0.589]$

Through this model, simply by putting SM and ST value Y' could be determined easily. If the value is higher than the cut off value, then the disease will take place. This study considered only two major independent variables (ignoring the other complex intermingled hidden factors that may influence the disease expression) which employ up to 62.34% variance in the dependent variable. Adjusted R^2 value indicates that the predictors chosen have influence on the disease severity. If other predictors added, R^2 value may increase but adjusted R^2 value will decrease but that might not have effect on the dependent variable.

Discriminant analysis: Further studies conducted to reveal how precisely the model can anticipate the disease severity (Table 3). The result divulged that for each additional unit increase in SM and ST the likelihood of getting the chance incremental disease risk group by 0.26 and 0.19 respectively which could be invariably used in predictive purpose. Therefore, in any given unit data of independent variables predicted disease severity could be easily estimated based on the cut-off value (=0.678) (Table 3). By determination of cut-off value through discriminant analysis situation would be predicted whether it falls in disease risk (if the value is above the cut-off value) or non-risk situation (if less than the cut-off value). p-value, precept both SM and ST and probably their combination too had a statistically significant effect on FWB as mentioned as p-value is less than 0.005 in both the cases. The SM and ST were plotted against the probability i.e. 0 to 1 to identify the event (disease risk) and the curve showed (Fig. 1), most of the observed data lies between the probability level 0 and 1 and the cut-off point also showing nearly 0.6 that do match with the determined cut-off value (=0.678) of the model. The correctness of the model computed 0.723 represented the accuracy of the model would be expected 72.3 % to predict the disease severity.

Adaptability of the model: To scrutinize the how far the model could be adapted two variables fitted probability (FITS_1) and delta deviance (DDEV_1) was introduced to decide over a particular event either disease risk or non-risk. Fitted probability was calculated and found that the data fit into the model with probability of 0.84 to 0.91 for being in state (1) i.e., disease risk period and is consistent in predicting disease risk. Whereas, low in predicting the second situation i.e., non-risk with probability 0.003 to 0.08 (Fig. 2). Delta deviance was used to show how far each event is from the pure fitted model. For better understanding these two variables were plotted against X and Y axis to display the deviance as a function of the fits to the model (Fig. 2). The Figure 2 shows two discrete curves involving two binary

Table 2. Goodness of fit

Method	Chi-square	P-value
Pearson	26.81	0.796
Deviance	17.90	0.923
Hosmer-Lemeshow	5.44	0.594

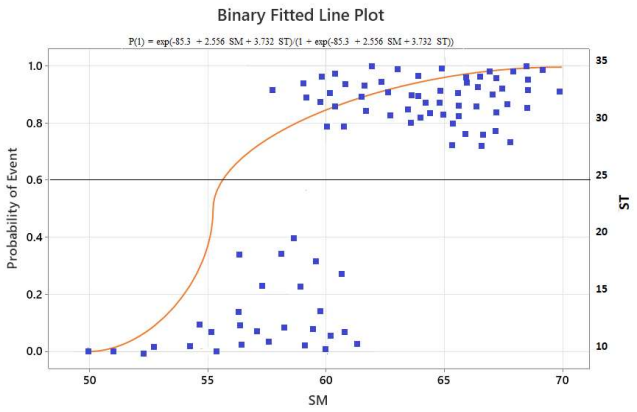

Fig. 1. Binary classification (Sigmoid graph)

Table 1. Binary logistic regression for predicting disease severity of fusarium wilt of banana

Predictor	Coefficient	SE	Z value	P-value	VIF	Odd ratio	95% CI	
Constant	-85.3	0.012	-3.47	0.008	-	-	Lower	Upper
SM	2.556	0.136	2.09	0.019	1.24	3.17	2.24	9.81
ST	3.732	0.234	0.15	0.024	1.24	1.08	1.35	2.67

SM = Soil moisture, ST = Soil temperature

Table 3. Discriminant analysis

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Cut off value	Correct proportion	F value
Inter Cept	-4.954	0.765	-5.128	0.0006	-5.367	-2.453	0.674	0.723	0.004
SM	0.263	0.058	2.354	0.001	0.012	0.058			
ST	0.196	0.023	1.374	0.002	-0.003	0.032			

SM = Soil moisture, ST = Soil temperature

states (disease risk and non-risk). From top left to bottom right relates to event 1(disease risk). The experimental data which is a good fit to the model should have low delta deviance with probability 1 corresponding to disease risk. The data points that fit well to the disease risk period are clustered in the bottom right. Contrarily, the data displayed at the top left represent poor fit to the model. The other line of the data representing the disease non-risk viz. the data points with low delta deviance represented by bottom left showed good fit with probability corresponding to non-risk and the point at top right characterize a poor fit of the model (Fig. 2).

Performance test of the model: The performance of the binary classifiers are evaluated by ROC (receiver operating characteristic) curve. This analysis is mandatory to decide the optimum cut-off value and to consider the optimal decision threshold. For a specified cut-off value either positive or negative diagnosis could be done for every unit by comparing the data to the cut-off value. Though, there are the probabilities that the predicted situation not always match to the actual condition and the probable outcomes could be true positive, true negative, false positive, and false negative. Here, ROC curve plays an important role that plots the true positive rate or sensitivity against the false positive rate (1-Specificity) (Fig. 3) for all possible cut-off which is essentially a trade-off between true positive and false positive. The ROC curve provides a pictorial presentation of the fitness of the forecasting model against the false-positive rates. The diagonal line is the reference line that classifies the condition randomly. The threshold points at which the ROC curve reaches closer to the top left corner are the best for maintaining a true positive rate. The area under the ROC curve also depicts the overall performance of the forecasting model by providing a numerical value and here the value is 0.823 which conferred a pretty good impression for the model to determine the disease risk period of FWB.

The model developed through this study is proved to be acceptable to forecast FWB in a particular SM and ST situation and could be an incorporated in future study of plant disease epidemiology and forecasting system to predict the apparent disease situation. This model would be a great support to the growers for timely adoption of disease management practices based on prevailing atmospheric conditions that are the prime factors for the development of soil borne fungal pathogens. Several workers worked on epidemiology and disease forecasting for different pathosystems like on phytophthora blight in potato by Do et al (2012), early blight in tomato by Saha and Das (2013) and on collar rot of chickpea by Tamang and Saha (2022). These models have been successful in guiding the farmers by critically predicting the probable time of initiation of the disease based on either soil temperature and moisture data

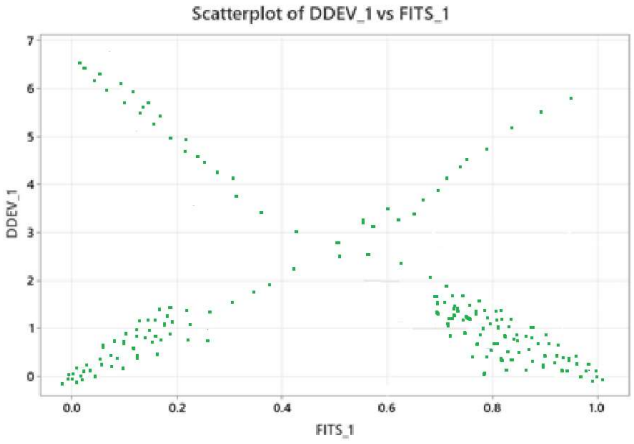

Fig. 2. Fitted probability Vs Delta deviance

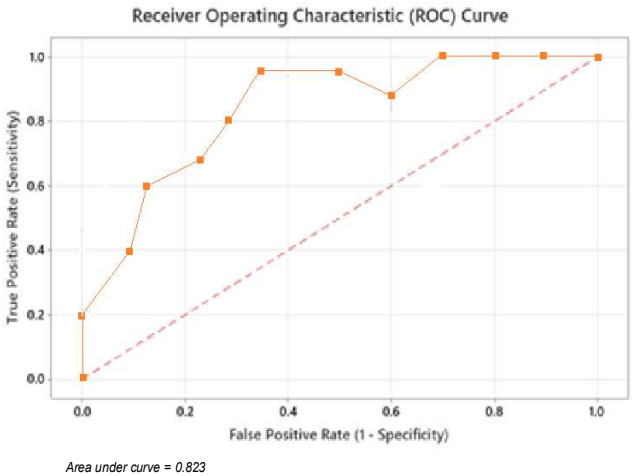

Fig. 3. ROC curve

or prevailing weather parameters and therefore guiding them toward the proper time for up-taking control measures.

CONCLUSIONS

Soil moisture and soil temperature are the critical factors for the development of fusarium wilt in banana. The combination of 60-65% soil moisture and soil temperature 30-35^{0}C are more conducive for the pathogen to create disease risk situation. Mathematical model developed and the accuracy of the model verified based on field data along with predicted disease situations which exhibited up to 72.3% precision in forecasting. Additionally, the threshold value determined from the realized data showed almost match with the predicted situation depicted through the model. Area under ROC covered 82.3% conveyed that the developed model would capably forecast the disease risk situation at any cut-off value by invalidating the effect of false-positive over true positive value. Therefore, it is highly imperative to have a precise tool to conjecture the situation vulnerable for ensuing the disease. Furthermore, when the disease occurs, the situation becomes pathetic for good crop stand leading toward total loss. This circumstance highly demands to have a definite forecast model to forewarn the farmers and the purpose has been served by this research. The present investigation holds scope to provide a vision to the researchers to develop a computer-simulated forecast model for fusarium wilt in banana.

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Development and Substantiation of Nano Formulation with Anti-viral Phtyomolecules Derived from Wild Papaya Genotypes for Extenuation of Papaya Ring Spot Virus (PRSV)

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***Abstract*:** Octadecanoic acid is a bioactive compound, a component of triglycerides reported to be present in *V. candamarcensis* and *V. cauliflora* which might have anti-viral activity against PRSV in papaya. The present study focused on the synthesis of nano emulsion of bioactive compounds using methods such as High energy homogenization and Sonication. The nano emulsion showed z-average diameter of 52.6 nm as spherical shaped droplet structure which was confirmed in TEM imaging. Plant bioassay was carried out for assessing the resistance activity of nano emulsion against papaya ring spot virus in papaya under a glasshouse condition using mechanical inoculation methods, in which pre-inoculation and co-inoculation methods with nano emulsion did not exhibit any symptoms of papaya ring spot virus infection in papaya seedlings. But in the post-inoculation method, treatments with Octadecanoic acid nano formulation had symptoms of papaya ring spot virus infection in papaya seedlings. Further studies are required to confirm the effective concentration of nano formulation of bioactive compounds for the control of PRSV infection at different growth stages.

***Keywords*:** Bioactive compounds, Octadecanoic acid, Nano-emulsion, Mechanical inoculation

Papaya (*Carica papaya* L.), a member of the Caricaceae family, has been planted in home gardens for centuries. Later on, it became a commercial and industrial crop due to the widespread usage of papain in the pharmaceutical and cosmetics sectors (Auxcilia et al 2020). Presently worldwide papaya production is threatened by the most destructive disease called papaya ring spot disease (Premchand et al 2021). Around the world, numerous initiatives, including a transgenic strategy, have been attempted to curb the PRSV incidence in papaya. Therefore, management of PRSV is required to reduce disease incidence and yield loss. Gohilapriya et al (2021) revealed the presence of a few bioactive compounds in wild genotypes of papaya such as *Vasconcellea cauliflora* and *Vasconcellea candamarcensis*, while it was absent in cultivated varieties. Among which, the compounds Octadecanoic acid and other phytomolecules were found in wild genotypes *viz., Vasconcelleae candamarcensis* and *Vasconcelleae cauliflora* had significance in possessing anti-viral properties. These compounds are reported to possess anti-viral activity against plant viruses. Gas chromatography–mass spectrometry (GC/MS) analysis was used to identify the existence of volatile antifungal chemicals in the bacterial secretome (Nakkeer*an* et al 2020). The antifungal chemicals pentadecanoic acid, n-hexadecanoic acid, octadecanoic acid (stearic acid) and tetradecanoic acid exhibited an increase in peak area with response to antifungal potential therapy. However, the above compounds are not hydrophilic in nature so that there is a need to convert them into hydrophilic for the applications in plants. Nanotechnology has significantly improved plant pathogen detection, crop protection, disease management, nutrient loss reduction in fertilization, plant germination, growth and plant-pathogen control in agricultural research. The development of nano chemicals has the potential to improve fertilizers, insecticides and plant growth. Plants use a variety of delivery systems, which include nanoparticles, nano capsules and nanoemulsions (Dutta et al 2022).

MATERIAL AND METHODS

High pressure homogenization: The microemulsion prepared was fed into high pressure homogenizer at high pressure for 5 to 10 cycles for homogenization.

Ultrasonication: Using a 24 KHz sonicator (Dr. Hielscher series, Model UP 400S), emulsification by sonication was done. The duration fixed was 30 minutes (ON/OFF for 5 seconds) with an amplitude of 60% and a temperature of 25°C.

Characterization of nanoparticles: The nanoemulsions were characterized using Particle Size Analyzer (PSA), Fourier Transform Infrared Spectroscopy (FTIR), Transmission Electron Microscope (TEM) and Scanning Electron Microscope (SEM).

Experimental details: Bioassay study was conducted at glasshouse, Department of Fruit Science, Tamil Nadu Agricultural University, Coimbatore. The assay was carried out by using completely randomized design (CRD) with eight treatments and with concentrations from 10-100 ppm.

Statistical analysis: The data collected during this research were pooled and analyzed using the MS Excel program and were statistically analyzed using R- Studio, AGRES software (0.74.0.0 version).

RESULTS AND DISCUSSION

The nano formulation of octadecanoic acid characterized in PSA for particle size has a mean droplet size of 313.9 nm, the zeta potential of 65.4 mV, and poly dispersity index of 0.398. This study technique produced more size reduction, poly dispersity index and zeta potential than previous research by Kumar and Randhawa (2015) that demonstrated the size of stearic acid solid lipid nanoparticles (SASLNs) greatly depends on the concentration of Gelucire® 50/13 in the solid lipid nano formulation with zeta average particle size of 1700 nm. The stretching of the methylene group (CH_3) in octadecanoic acid nano emulsion was represented by the peak 2937cm^{-1} which was similar to the FT-IR results of Neg*i* et al (2014). The findings of TEM showed that the Octadecanoic acid nano formulation was having a spherical shape droplets with the nano range of (52.6 nm). Earlier Cryo-TEM method was incorporated to validate the particle size as well as to characterize the stearic acid nano emulsion shape and structure, reported that their micrographs obtained using an Ultras can XP camera at a nominal magnification of 25,000x and a defocus of 200nm showing well-defined spherical shapes of the droplets in the nano-system of astaxanthin encapsulated in stearic acid nano emulsion (Flores-Miran*da* et al 2020). The SEM image of octadecanoic acid nano formulation confirmed that they are spherical. From the SEM images of the octadecanoic acid, it could be concluded that the formulation was in the nano range of 644.1 nm which was similar to the report of (W*ang* et al 2011) where SEM was used to examine the surface morphology of copper foils with stearic acid and numerous nanosheets with various shapes are randomly dispersed across the surface with the flexible micro-nano sheet thickness of around 500 nm.

The symptoms were measured at two intervals on the 15th and 30th days after pre-inoculation, post-inoculation and co-inoculation (Sangeetha et al 2020). On15th and 30th day of pre-inoculation and co-inoculation, there were no symptoms observed on the plants, The absence of symptoms in the present study might be due to the inhibitory effects on DNA replication and antigen production by octadecanoic acid nano formulation. Li et al (2010) elaborated the delivery strategy of stearic acid-g-chitosan oligosaccharide polymeric micelles for lamivudine stearate and its antiviral activity by, in which the prodrug of lamivudine (Ia), lamivudine stearate , was produced via ester linkage between LA and stearic acid to boost the lipophilicity of a water-soluble antiviral drug. When compared to LA and LAS, Stearic acid-g-chitosan oligosaccharide (CSO-SA) on *in vitro* showed anti-HBV (Hepatitis B Virus) actions with pronounced inhibitory effects on DNA replication and antigen production.

The symptoms on 15th day of post-inoculation showed that the percentage of disease severity was the highest in treatment T_8 (Inoculated control) with 30.5 % followed by the treatment T_1 (stearic acid 10 ppm) 29.4 % and lowest in treatment T_5(stearic acid 100 ppm) with 20.3 % on 30th day of post-inoculation. The disease severity was highest in treatment T_8 (inoculated control) with 56.3 % followed by treatment T_1 with 47.3 % and lower in treatment T_5 with 39.2

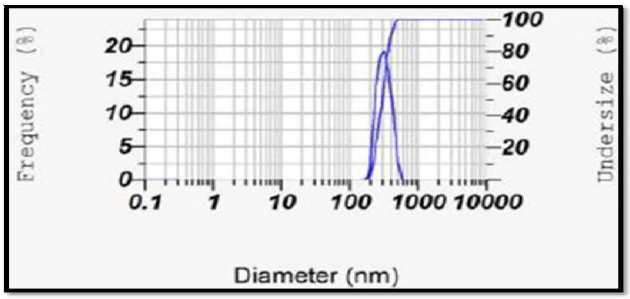

Fig. 1. Size of octadecanoic acid nano formulation during synthesis

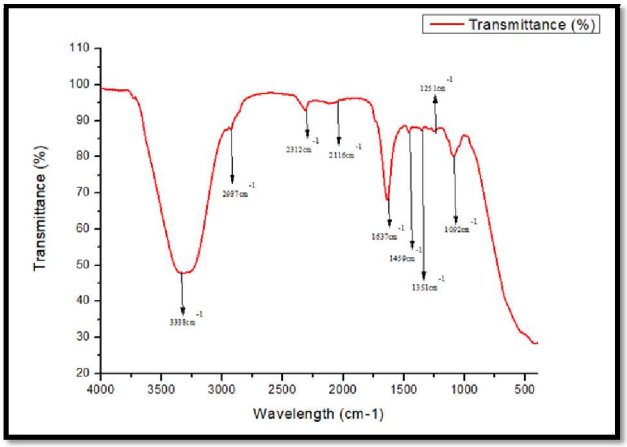

Fig. 2. FTIR spectrum of Octadecanoic acid nano emulsion

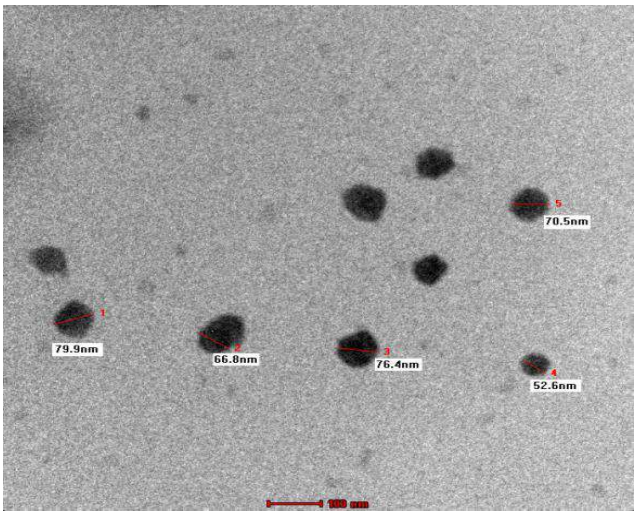

Fig. 3. TEM image of Octadecanoic acid nano emulsion

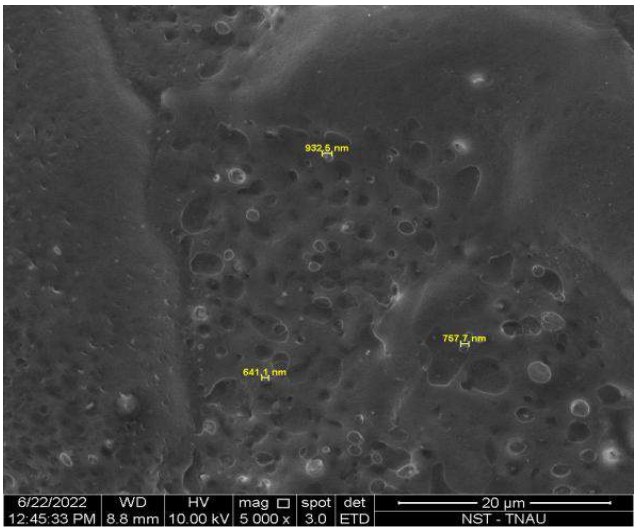

Fig. 4. SEM image of Octadecanoic acid nano emulsion

Table 1. Assessment of PRSV disease severity with application of octadecanoic acid nano formulation

Treatment (Days)	Post-inoculation (%)	
	15th (DAI)	30th (DAI)
T1	29.4	47.3
T2	27.8	45.7
T3	25.9	41.2
T4	25.2	39.4
T5	20.3	39.2
T6	0	0
T7	0	0
T8	30.5	56.3
Mean	19.8	32.3
CD (p= 0.05)	1.12	1.45

%. The concentration of 100ppm of octadecanoic acid nano formulation spray had maximum effect on plant height, leaf area, stem girth and the number of leaves in all inoculation methods Xiong et al (2020) observed that octadecanoic acid possesses not only antiviral properties but also antibacterial, antimicrobial and antifungal properties in plants.

CONCLUSION

The study proved the efficacy of nano formulations of bioactive compounds derived from wild papaya genotypes in inducing resistance against PRSV infection in domesticated papaya plants (TNAU papaya CO.8) that are vulnerable to PRSV. Moreover, the biosafety of the nano formulation was ensured through dose specific threshold limit of maximum 100 ppm while the efficacy was registered from 10 ppm onwards and the study must be continued for molecular level analysis and field trials to confirm the efficacy of bioactive compounds nano formulation against the papaya ring spot virus.

AUTHORSHIP CONTRIBUTION

Ramya S: Investigation, Writing-original draft, J. Auxcilia: conceptualization, methodology, validation, investigation, Jeya Sundara Sharmila: methodology for nanotechnology, K. Hemaprabha: resources, K.S. Subramanian: technical support for nanotechnology.

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Histological and Biochemical Evidence of Zinc Toxicity in White Leg Shrimp, *Litopenaeus vannamei* Boone

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***Abstract*:** In an in-vitro study conducted during June to October 2021, the effect of zinc sulphate on the biochemical and histological parameters of *Litopenaeus vannamei* was evaluated at six different doses: 0.5, 1, 2, 4, 6, and 8 mg/L. The higher doses of zinc sulphate were toxic to *L. vannamei* and there were significant changes in the biochemical and histological parameters of vannamei exposed to increasing concentration of zinc sulphate. At higher concentration (8mg/L), a decrease in R-cells, F-cells, B cells, and E-cells, low hemocyte count, high hemolytic infiltration, abnormal lumen, necrosis, and melanization were observed in hepatopancreas. In gills, gill lamella was found to be fused, pillar cells became interspersed, and show large deformities in comparison to control. In the intestine, maximum height of the epithelial cell was seen in control which continuously decreases with the increasing concentration of zinc sulphate. The increasing doses of zinc sulphate showed significant differences in total hemocyte count (THC) of shrimp. The total hemocyte count (THC), total granulocyte counts (TGC), and total agranulocyte counts (TAC) of shrimp were significantly lower in $ZnSO_4$ 8mg/L (14.45, 10.51 and 3.94 in comparison to control (25.18, 17.50and 7.83). Total hemocyte counts is an indicative of health marker for shrimp which showed gradual decrease at higher concentrations.

***Keywords*:** Biochemical, Haemocytic infiltration, Histological changes, *Litopenaeus vannamei*, Necrosis

Heavy metals are well known for their significant contribution in environmental pollution which has gained prominence in the recent years (Chen et al 2020). Many of these metals exist naturally in the environment and are required in trace amount for metabolism of aquatic species. These substances enter the environment through manmade and natural sources, where mostly they form complex with other substances that harm the ecosystem (Häder et al 2020). However, the industrial and agricultural pollutants have aided in increasing the natural levels of such metals in the aquatic environment in. Metals in the marine/estuarine aquatic environment are of ecotoxicological significance because they can disrupt physiological processes such as osmoregulation, respiration, and growth. The hepatopancreas, analogous to liver performs many functions of liver, intestine and pancreas in vertebrates as well as various metabolic processes in crustaceans (Vogt 2019). According to a previous work on the hepatopancreas at different levels *viz*. anatomy, physiology, metabolism, biochemistry, and development, it also performs a variety of other functions such as absorption, digesting, storage, and secretion (Satgurunathan et al 2022). Although, mostly the detoxification processes in crustaceans is performed by hepatopancreas, some xenobiotics, such as pesticides and aflatoxin, are likely to impair the structure and functioning of this organ in aquatic crustaceans (Campbell et al 2022). These compounds have been reported and proven to cause toxicity, resulting in histological alterations in hepatopancreas, gills, and intestines of the investigated species. The primary goal of this study was to investigate effect of zinc on biochemical and histological alterations in the hepatopancreas, gills, and intestine of *L. vannamei*.

MATERIAL AND METHODS

Experimental design: The experiment was conducted for four months, from June to October 2021, at Chaudhary Charan Singh Haryana Agricultural University Hisar, India. *L. vannamei* juveniles were taken from a commercial shrimp farm in Hisar and brought to the laboratory in live condition. After three days of acclimatization, *L. vannamei* juveniles were transferred to experimental aquaria (100 liters each) at a stocking density of five juveniles per tank filled with saline water (20 ppt). To keep the temperature stable (27±0.5°C), each tank was outfitted with a filter, submerged air diffuser, and submersible heater. Due to its prevalence in shrimp tissue, zinc was chosen for the experiment. $ZnSO_4$ salt was used to prepare the stock solution. Six different doses *viz*. T1-T6 of $ZnSO_4$ (0.5, 1, 2, 4, 6 and 8 mg/L) were prepared in triplicates from stock solution and were determined by Atomic Absorption Spectrum (AAS).

Morphological and behavioral changes: The morphological and behavioral alterations in *L. vannamei* were detected during the experiment. The exoskeleton, gills, appendages, telson, and uropod were examined and any

color changes was observed for morphological modifications. The behavioral alterations were recorded throughout the study by observing their movement patterns and swimming habits.

Histological examination: During the experiment moribund shrimp from a different aquarium were collected and injected with Davidson's fixative in hepatopancreas and posterior abdominal regions. Post injection, the shrimps were preserved in the same fixative for 24 hours. Shrimp was dissected and longitudinal body section of different body parts were allowed to dehydrates in 70, 80, 96, and 100% ethanol, then cleared with xylene, embedded in paraffin waxes. Thin sections of tissue were cut at size of 5µ were using a manual microtome. Each sample was rehydrated and stained with hematoxylin and eosin dye.

Total hemocyte count: Shrimp were chosen at random from each treatment. 0.8 ml of blood was collected using the 1 ml hypodermic syringe (26-gauge) from the ventral sinus of shrimp in the first abdominal segment. Each syringe had 0.2 ml of anticoagulant (pH 7.6, 250 mM sucrose, 10 mM Tris-HCl, 100 mM sodium citrate) prefilled. To achieve an equivalent volume ratio of hemolymph to the anticoagulant, more anticoagulant was injected. Anticoagulated hemolymph of about 50 µl volume were kept frozen for 30 minutes in an equivalent volume of neutral buffered formalin (10% NBF) to determine the total hemocyte count (THC) and differential hemocyte counts (DHC). The remaining anticoagulated hemolymph was centrifuged at 300g in 4°C for 10 min to separate the hemocytes from plasma. Phosphate buffer saline (PBS) (pH 7.2, 20 mM) was used to dilute fixed hemolymph 2, 4, 8, 16, and 32 times. Fixed hemolymph was spread on a slide and stained with 10% Giemsa solution, kept for 10 minutes. Tsing et al (1989) were then used to characterize the differential hemocytes.

Total hemocyte count (THC): For total hemocyte counting, a drop of anticoagulant mixed hemolymph (1:1) was transferred to a Neubauer hemocytometer kept under the light microscope in100x magnification (Wootton and Pipe 2003). THC was calculated as total hemocyte cells per ml of hemolymph.

$$\text{THC ml}^{-1} = \frac{\text{Average haemocyte cell count per square} \times \text{dilution factor}}{\text{Number of square counted} \times 10^{-6}}$$

Differential hemocyte count (DHC): After counting total hemocytes, they were differentiated into granulocytes and agranulocytes (hyaline cells) based on granular content and expressed as total granulocyte cells per ml (TGC ml^{-1}) and total agranulocyte cells count per ml (TAC ml^{-1}) using the formulas below.

$$\text{TGC ml}^{-1} = \frac{\text{Average granulocyte cell count per square} \times \text{dilution factor}}{\text{Number of square counted} \times 10^{-6}}$$

$$\text{TAC ml}^{-1} = \frac{\text{Average agranulocyte cell count per square} \times \text{dilution factor}}{\text{Number of square counted} \times 10^{-6}}$$

RESULTS AND DISCUSSION

Morphological and behavioral: Shrimp exposed to higher doses of zinc sulphate, developed black spots on their body, telson, and carapace region. Slow and sluggish movement of the pleopods, less feeding, and erratic movement were recorded during the experiment.

Effect on hepatopancreas: The hepatopancreas of vannamei as observed in control has a well-organized glandular tubular structure**.** The hepatopancreas consists of hepatopancreas tubules and four types of cells: E- cells (embryonic or “embryonalzellen”), F-cells (“fibrillenzellen” or fibrous), R-cells (“restzellen”), and B-cells (“blasenzellen”). The cells exhibited normal structural differentiation into E-cells at the distal end of the tubule, young R -cells and F -cells at a short distance from the distal region, and B- cells in the middle region and proximal end of the tubules. The B-cells have large sized apical secretory granules, the R-cells were loaded with large amounts of rough endoplasmic reticulum (RER) and small lipid droplets, while the F-cells were non-vacuolated and well stained. The lumen of tubules has a normal “star-like” appearance. Tubules were lined by a single layer of epithelial cells and have normal interstitial sinus between them. The structure of hepatopancreas in treatments from T1-T6 (Fig. 1) (0.5mg\L to 8mg/L) was not normal. Hemocyte infiltration (HI), abnormal lumen (ALU) in the interstitial sinus (IS) was observed in the hepatopancreas of vannamei exposed to T2 (1mg/L) and T3 (2mg/L) treatments. In treatment T3-T4 (4mg/L-6mg/L), distinct structural alteration was seen whereas in treatment T1(0.5mg/L) and T2 (1mg/L) observed alterations include., necrotic tubules (NT), melanization (MZ), separation of necrotic tubules of hepatopancreas (NCH), tissue debris in lumen (TD), coagulation in thickened basal laminae (CO) and walling of tubules by hematocytes around basal laminae. Vacuolation was observed in hepatopancreas tissue in all treatments. The exposure of shrimp to very low levels of zinc in the environment resulted in various physiological, biochemical, and histological changes in vital organs and tissues (Frías-Espericueta et al 2008). Findings of Liang et al (2022) also suggest that exposure to zinc enhanced Zn buildup in the hepatopancreas, changed immunological, antioxidant, and detoxifying responses via controlling the gene expression of associated genes, and ultimately could cause apoptosis. Due to zinc toxicity cellular differentiation of hepatopancreas altered resulting in large deformities. The B-

cells which is responsible for the formation of digestive enzymes are reduced in stress condition. The R-cells act as nutrient reserve in the hepatopancreas (Ruiz et al 2022). Hence, upon reduction of R-cells, it may be due to a large fluctuation in demand for osmoregulation (Li et al 2022). This suggested that exposure to zinc has an impact on physiology and resulted in histological alterations in shrimp.

Histological effect on gills: The cellular differentiation in gills was found to be normal in control and T1 (0.5mg/L). The primary gill filaments were branched from the central axis and the secondary gill lamellae showed a finger-like appearance. The secondary lamellae were attached to primary lamellae. The cellular structure of gills in T2-T3 (Fig. 2) (1 mg/L-2 mg/L) exhibited a fusion of gill lamella and showed large vacuolation. In T4 (4mg/L), gill lamella was found to be fused which created a large void in cellular space. In T5 and T6 (6mg/L- 8mg/L) pillar cells became interspersed and show large deformities in comparison to control. Gills are more prone to environmental pollution. The cellular structure of vannamei in T2-T3 (1mg/L-2mg/L) exhibited a fusion of gill lamella and large vacuolation. In T4 (4mg/L) treatment gill lamella was found to be fused which created a large void in cellular space. In T5 (6mg/L) and T6 (8mg/L) pillar cells became interspersed and exhibited more deformities in comparison to other treatments. The zinc disrupts the normal organization of the gill and reduces the oxygen consumption of shrimp. At higher concentrations, it was difficult to distinguish the cellular structure of gills and resulted in 100%

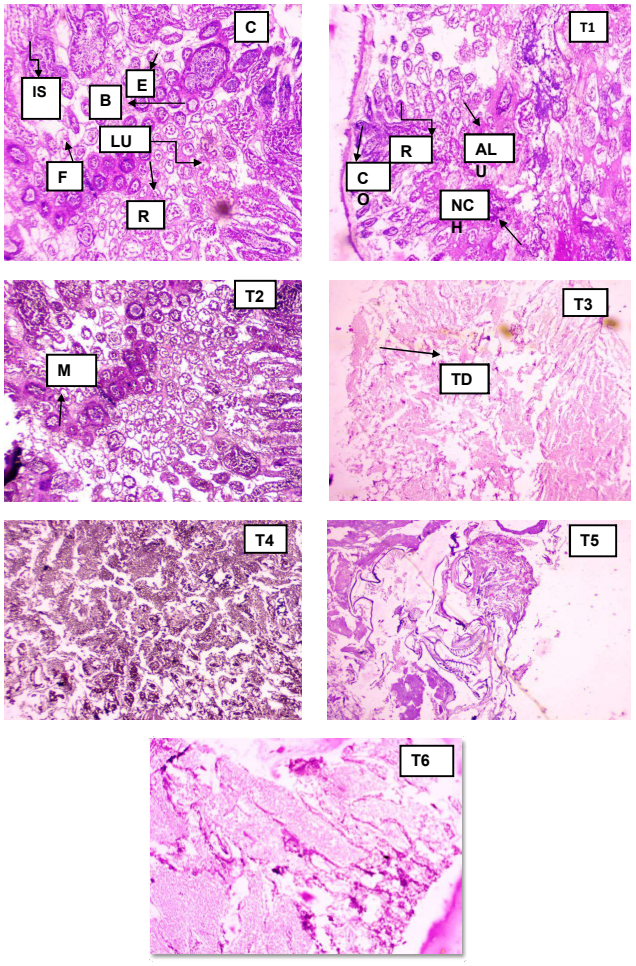

Fig. 1. Typical organization of juvenile *L. vannamei* hepatopancreas of control (C) and all treatments i.e., T1, T2, T3, T4, T5, and T6 at 10X magnification. ALU= Abnormal Lumen; E=Embryonic Cells, B= B-cells (Blasenzellen cells) with their large apical secretary vacuoles, IS= Interstitial sinuses, LU= Lumen; R= R-cells (Restzellen cells), Coagulation (CO), Melanization (M); F=F-cells (Fibrillenzellen cell)

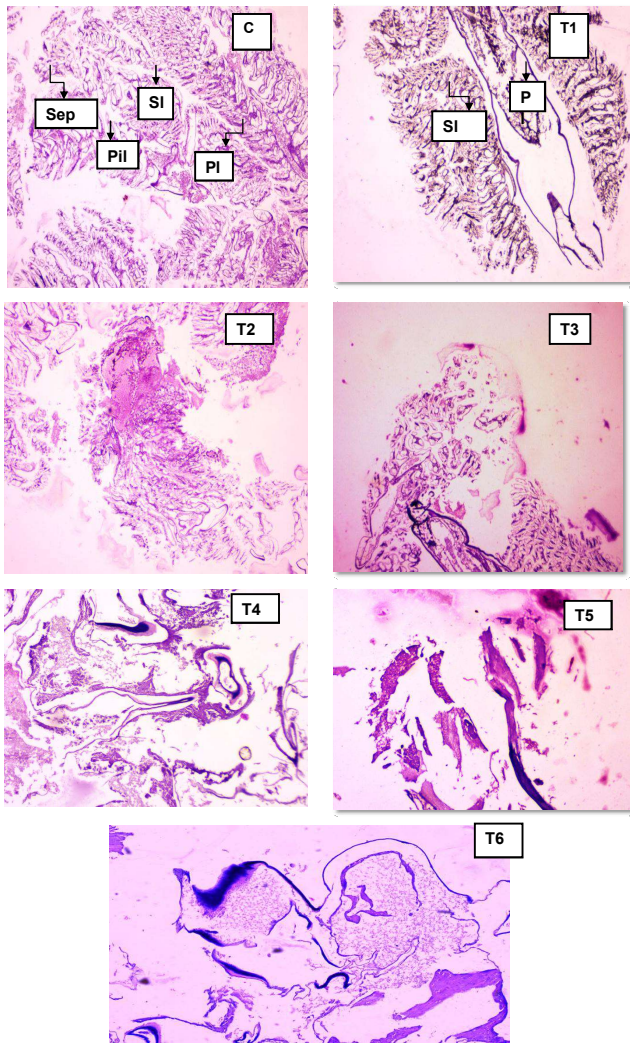

Fig. 2. Typical organization of juvenile *L. vannamei* gills in control (C) and all treatments i.e., T1, T2, T3, T4, T5, and T6 at 10X magnification. PL- Primary lamellae, SL- Secondary lamella, Pil- Epithelial pillar cell processes, Nec- Cell necrosis, Sep- septum

mortality as seen in treatment T4-T6. Due to prolonged exposure to zinc secondary lamella fused and appears as an undifferentiated mass and ladder-like arrangements of pillar-like cells become collapsed (Amoah et al 2022).

Effect on the intestine: The intestine in control has a normal structure with epithelial cells and columnar villi, intestinal crypts. In treatment T1 (0.5 mg/L) there was a minor alteration but in T2-T3 (1 mg/L-2mg/L) it was observed disruption of epithelial cells and large deformities in crypts. In treatment T4 (4mg/L), T5 (6mg/L), and T6 (8mg/L) intestine was completely damaged and there was no cellular differentiation in epithelial cells, villi, and crypts (Fig. 3). It was assessed that zinc was highly toxic for shrimp and resulted in large deformities of intestinal tissue. Maximum height of epithelial cells continuously got decrease with increased concentration of zinc sulphate. Zinc is highly toxic for shrimp and resulted in deformities of intestinal tissue. It observed that there was maximum height of epithelial cells which continuously decreases with an increase in the concentration of zinc (Nagarjuna et al 2019, Khushbu et al 2022). To consider a crustacean as "healthy", a sufficient number of circulating hemocyte cells must be present as hemolymph helps in maintaining homeostatic integrity.

Total haemocyte count (x 10^6 cells ml^{-1}): The effect of zinc sulphate on the total haemocyte counts (THC), total granulocyte counts (TGC), and total agranulocyte counts (TAC) of *L. vannamei* juveniles at the end of the study are (Table 1 and Fig 4). The increasing level of zinc sulphate showed significant differences in (THC) of shrimp. The total haemocyte count (THC), total granulocyte counts (TGC), and total agranulocyte counts (TAC) of shrimp were significantly lower in $ZnSO_4$ 8mg\L (14.45, 10.51 and 3.94) than in control (25.18, 17.50 and 7.83). Haemocyte number monitoring has

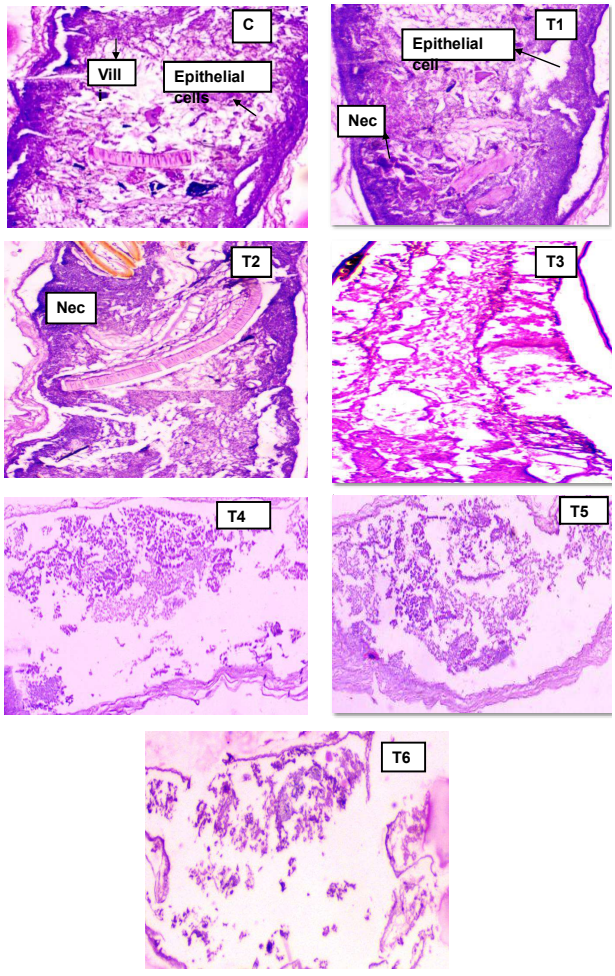

Fig. 3. Typical organization of juvenile *L. vannamei* intestine in control (C) and all treatments i.e., T1, T2, T3, T4, T5, and T6 at 10X magnification

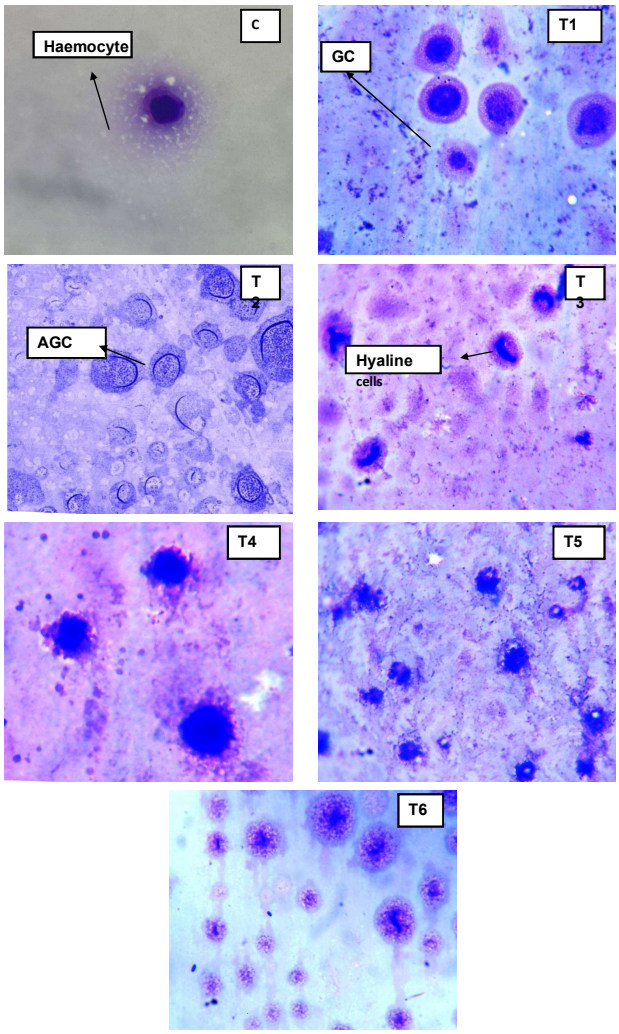

Fig. 4. Typical organization of the Haemocytes of control (C) and all treatments i.e., T1, T2, T3, T4, T5, and T6 has done at 100X magnification of juvenile *L. vannamei*, Granulocyte count (GC), agranulocyte count (AGC)

Table 1. Effect of zinc toxicity on the hematological parameters of *L. vannamei* (Mean±SE) recorded at the at end of study period

Treatments (mg/L)	THC (x 10^6 cells ml^{-1})	TGC (x 10^6 cells ml^{-1})	TAC (x 10^6 cells ml^{-1})
Control	25.183±0.533	17.500±0.433	7.833±0.120
$ZnSO_4$ 0.5	24.283±0.429	16.583±0.303	7.400±0.153
$ZnSO_4$ 1	21.720±0.711	14.820±0.930	6.900±0.306
$ZnSO_4$ 2	19.083±0.480	13.170±0.793	6.100±0.265
ZnSO4 4	17.860±0.175	12.260±0.525	5.600±0.351
ZnSO4 6	16.163±0.276	11.350±0.578	4.880±0.386
ZnSO4 8	14.457±0.609	10.513±0.399	3.943±0.228
CD (p=0.05)	1.386	1.845	0.839

been proposed by Duarte and Caçador (2019) as a measure of stress and/or physiological state in crustaceans, but their predictive significance in the evaluation of health status and immunological competence has not been adequately examined. Most importantly, it is to be known the sufficient amount of hemocyte number. Sabu and Gopal (2016) observed that total and differential number of hemocytes in crustaceans may vary significantly, and these variations are assumed to be correlated with life stage, moult cycle, level of nutrition, disease, and physiological or environmental conditions. In the current work, the mean number of hemolytic cells in control shrimp served as a baseline for comparison with the number of shrimps exposed to various harmful metal doses. The results demonstrated that hemocyte numbers showed reduction at all concentrations of exposure to zinc sulphate. A further research needs to be done on hemocyte counts as a biomarker of 'health' in crustaceans.

CONCLUSION

There were significant changes in the biochemical and histological parameters of vannamei exposed to increasing concentrations of zinc sulphate. At higher concentrations (8mg/L), a decrease in R-cells, F-cells, B cells, and E-cells, low haemocyte count, high haemocytic infiltration, abnormal lumen, necrosis, and Melanization in hepatopancreas were recorded. In gills, gill lamella was found to be fused, pillar cells became interspersed, and show large deformities in comparison to control. In the intestine, there was a maximum height of the epithelial cell in control which continuously got decrease with increasing concentration of zinc sulphate. Total haemocyte count was used as a health marker for shrimp which gradually decrease at high concentrations. Additionally, it is important to take into account and will be further researched how heavy metals affect the capacity and effectiveness of the hepatopancreas, gill, and gut to bio transform other environmental contaminants.

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Effect Vegetable Oils on Growth, Feed Utilization and Digestive Enzyme Activities of *Labeo rohita* (Hamilton 1822)

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***Abstract*:** The present study was aimed to evaluate the effect of selected vegetable oils on growth, feed utilization and digestive enzyme activities of *Labeo rohita*. A 60-day trial was conducted using flour vegetable oils sunflower, mustard, sesame oil) and soybean oil along with control. Oils were supplemented at 10 % in the basal diet. One hundred fifty fingerlings were stocked in fifteen tanks and fed at the rate of 3 percent of body weight twice a day 1000 and 1700 hours) for 60 days.The weight gain (g), per cent weight gain and specific growth rate were significantly higher in soybean oil (60.08 and 0.78) followed by mustard oil sesame oil. Significantly the improved feed conversion ratio also showed similar trend. Similarly, gross conversion efficiency and protein efficiency ratio were also improved in the soybean oil. The amylase and protease activities did not show significant difference while lipase activity was significantly improved in control and treatments. From the present study use of the oils in basal diet promote growth, with the highest growth enhancement from soybean oil.

***Keywords*:** Sunflower, Significantly, Efficiency, Lipase, Protease

Indian major carps *viz*. *Labeo rohita, Catla catla* and *Cirrhinus mrigala* are the prime species cultivated in the inland freshwater aquaculture systems of India. Among the three Indian Major carp species, Rohu is highly preferred by the farmers mainly due to its higher growth rate, market demands and consumer preference (Nair and Salin 2007, Mahapatra et al 2012). *Labeo rohita* is a fast-growing species and attains about 35-45 cm total length and 700-800 g weight in one year under normal conditions. Generally, in polyculture, its growth rate is higher than that of Mrigal but lower to that of catla (FAO 2009). In aquaculture, feed accounts for 60-70 percent of the entire production cost which is why cost-effective feed management is the key to farming success. For growth, reproduction and other body functions, a balanced amount of protein, fat, vitamins and minerals in fish feed is a necessity. Different types of feed ingredients are used in fish food formulation such as plant and animal-based ingredients, groundnut oil cake, rice bran, wheat flour and fish meal, etc.

Vegetable oils are used as an alternative to fish oil (Dalbir et al 2015). They are cheap and less harmful to the natural aquatic system. Further, the feed supplementation with vegetable oils will not alter the organoleptic properties of the fillets and will be highly digestible for fish. Dietary lipids play an important role as a good supplier of energy, essential fatty acids and soluble vitamins. The addition of lipids in fish feed contributes to protein sparing by increasing their digestible energy value (Ayisi et al 2019). Substitution of fish oil in aqua feeds has become inevitable due to the limited global supply of fish oil (Dalbir et al 2015). In fish diet, oils are essential compounds as they play an important key role in enhancing growth. Oils are the principal source of omega-3 and omega-6 fatty acids. In fish diet, lipids are added as per the requirement of individual species. The oils added to the fish diet act as antimicrobial, anti-oxidative and growth promoter agent. Besides, oils also enhance the palatability, digestibility and binding capacity of the feed (Yadav et al 2019). The use of vegetable oils (Soybean and linseed oils) is considered as a good source of lipid in salmonids or freshwater fish diet (Bell et al 2001, Rosenlund et al 2001, Caballero et al 2002). The marine fish species are not capable to exchange linoleic or linolenic acids of vegetable oils, into arachidonic, eicosapentaenoic (EPA) or docosahexaenoic acids (DHA). These are impotent for marine fish and are available in vegetable oils in high quantity. Provided that essential fatty acid requirements of finfishes were met, partial replacement (60-75%) of fish oil with lipid source did not affect the fish performance (feed efficiency, growth, feed intake, etc.) significantly (Turchini et al 2009). The present study was aimed to evaluate the efficacy of selected vegetable oils concerning fish growth and other feed utilization parameters.

MATERIAL AND METHODS

The study was conducted from November 8 to January 8,

2019, at MPUAT, Udaipur (Rajasthan). Fingerlings of *Labeo rohita* (Hamilton 1822) were procured from the Aquaculture Research unit MPUAT fish farm. The fingerlings were healthy and free of any infection. Initially, the fingerlings were conditioned for 15 days in fibre reinforced plastic (FRP) tanks.

Experimental detail: The experimental diet was prepared by adding selected vegetable oils in the basal diet. Treatment groups were incorporated with different vegetable oils such as sunflower (T_1), mustard (T_2), sesame (T_3) and soybean oil (T_4) each @10 percent in the basal diet. The experiment was conducted in triplicate following completely randomized design for 60 day. The dry ingredients of the basal diet (groundnut oil cake, rice bran and wheat flour) were thoroughly mixed into dough and were placed in an autoclave at 15 lbs pressure for 30 minutes. After cooling, vegetable oil and mineral mixture were added and pellets were prepared by using a hand pelletizer. Thus, the prepared vermicelli (2.0 mm diameter) was air-dried and stored in airtight containers (Table 1). The experiment was conducted in 200-liter rectangular plastic tanks. Each tank was washed before the introduction of fish. All the experimental tanks were cleaned and filled with filtered tube well water. Each tank was stocked with 5 fingerlings of almost in equal size. The experimental fish were fed @ 3 per cent of body weight twice a day (10 00 and 1700 hours) in two split-dosages for 60 days.

Water quality sampling: The quality of experimental waters (i.e. temperature, pH, dissolved oxygen, alkalinity, electrical conductivity and total dissolved solids) was monitored on the initial day and subsequently after every 15 days. Water quality parameters were analysed following the standard methods of APHA (2005).

Growth parameters: At the end of the experiment, all the fishes from experimental tanks were harvested with a hand net. The weight of individual fish was measured. The growth parameters were calculated.

Weight gain (g) = Final weight (g) – Initial weight (g)

$$\text{Specific growth rate \%} = \frac{(\text{Log Wt} - \text{Log W0})}{\text{D} \times 100}$$

Where, Ln = Natural log; W_0 = Initial fish weight (g); W_t = Final fish weight (g); D = Duration of feeding (days)

$$\text{Gross conversion efficiency} = \frac{\text{Weight gained (g)}}{\text{Food given (g)}}$$

Feed utilization parameters: The feed utilization parameters such as feed conversion ratio (FCR) and protein efficiency ratio (PER) were calculated.

$$\text{Feed conversion ratio} = \frac{\text{Food given (g)}}{\text{Weight gain (g)}}$$

$$\text{Protein conversion efficiency} = \frac{\text{Total wet weight gained}}{\text{Crude protein fed (\%)}}$$

Digestive enzyme activities: Lipase was analyzed by the method of Cherry and Crandall (1932). Protease was analyzed by the casein digestion method Drapeau (1997) while amylase was determined by the dinitro-salicylic-acid (DND) method of Rick and Stegbauer (1974).

Energy value of diet: The energy value of experimental diet was calculated by method of Halver (1976).

Energy (kcal/100g) = protein (%) x 4.5 + lipid (%) x 9.5 + carbohydrates (%) x 4.

Statistical analysis: The data were statistically analysed by using SPSS 16.0.

Table 1. Feed composition (Ingredients g/kg)

Particular	Experimental diet				
Diet Ingredients (g/100g)	T_0	T_1 (Sunflower oil)	T_2 (Mustard oil)	T_3 (Sesame oil)	T_4 (Soybean oil)
Basal diet*	100	90	90	90	90
Vegetable oils**	00	10	10	10	10
Total	100	100	100	100	100
Proximate composition (%)					
Moisture	10.40	10.28	10.23	10.18	9.87
Crude protein	24.56	23.52	23.34	23.29	23.48
Fat	7.58	17.38	17.30	17.25	17.42
Ash	6.40	6.34	6.45	6.24	6.20
Carbohydrates	61.46	52.76	52.76	53.22	52.60
Energy (kcal/100g)	428.37	481.99	480.42	481.55	481.55

*Basal diet constitutes groundnut oil cake, rice bran, wheat flour which was taken in the ratio of 40: 40: 20, respectively.
**Vegetable oils: Sunflower oil; Mustard oil; Sesame oil; Soybean oil

RESULTS AND DISCUSSION

Water quality: The water quality did not differ significantly in different treatments (Table 2).

Growth

Weight gain (g): The net weight was significantly higher in treatments than t in T_0 (4.017g). The significantly higher growth was in T_4 (7.417g) followed by T_2, T_3, T_1 and T_0 (Table 3). The significantly higher growth rate in vegetable oil supplemented diet fed fish has also been reported by different workers (Abbas 2007, Dalbir et al 2015, Zupan et al 2016).

Weight gain (%): The per cent weight gain was significantly higher in all treatments than in T_0 (32.71%). The significantly higher growth was in T_4 (60.076%) followed by T_2, T_3, T_1 and T_0 (Table 3). Zupan et al (2016) also concluded that the soybean oils significantly increase the fish per cent weight.

Specific growth rate: The specific growth rate was significantly increased in treatment. The significantly higher growth was in T_4 (0.784) followed by T_2, T_3, T_1 and T_0 (Table 3). Gandotra et al (2017) also concluded the vegetables oils directly impact the fish growth parameters like SGR, FCR, and GCE etc.

Gross conversion efficiency: The gross conversion efficiency was significantly higher in all treatments than in T_0 (0.16g). The significantly higher growth was in T_4 (0.27g) followed by T_2, T_3, T_1 and T_0 (Table 3). Figueiredo et al (2005) also observed that replacement of fish oil with soybean oil had no adverse effect on fish gross conversion efficiency.

Feed utilization parameters: The feed utilization was significantly different among all treatments.

Feed conversion ratio: The feed conversion ratio was significantly higher in control diet (T_0) as compared to other treatments (T_4 T_2, T_3 and T_1). The significantly higher growth was in T_4 (3.76) followed by T_1, T_3, T_2 and T_0 (Table 3).

Protein efficiency ratio: The minimum (0.163) and maximum (0.322) PER were in T_0 and T_4 respectively. PER within treatments and between treatments were significantly different (Table 3). Parallel results have been found for turbot fed a soybean oil (SO) containing diet after a re-feeding period of 8 weeks with a 100 per cent fish oil diet.

Digestive enzyme: Activity of amylase and protease did not show significant difference while lipase activity was significantly different among the experimental groups. The lipase activity was significantly higher in treatment groups than that of those in T_0. The lowest (0.79) and highest (3.35) lipase were in T_0 and T_4. In fish, protease is a major group of digestive enzyme which hydrolyzes the bonds of peptide

Table 4. Effect of selected vegetable oils on amylase, protease and lipase in intestine of *L. rohita*

Treatments	Amylase (min/gm/protein)	Protease (min/gm/protein)	Lipase (mg protein)
T_0	4.69	0.202	0.79
T_1	4.51	0.240	1.45
T_2	4.09	0.238	1.26
T_3	4.88	0.233	1.17

Table 2. Range of selected water quality parameters

Parameters	T_0	T_1	T_2	T_3	T_4
Temperature (^{0}C)	14.8-23.5	14.7-23.5	14.7-23.7	14.9-23.7	14.9-23.8
pH	8.0-8.4	8.0-8.3	7.9-8.4	8.0-8.3	8.0-8.3
Alkalinity (mg/l)	110-140	120-130	120-130	110-140	112-134
Dissolved oxygen (mg/l)	5.6-8.8	4.8-8.0	4.8-8.0	5.6-7.2	5.6-8.0
TDS (mg/l)	830-920	850-990	810-930	840-950	840-940
EC (µS/cm)	1640-1950	1700-1960	1700-1950	1710-1960	1700-1920

Table 3. Summary data on growth performance of *L. rohita* fed with different vegetable oils supplementation diet

Treatments	Parameters							
	Initial weight (g)	Final weight (g)	Net weight gain (g)	Per cent weight gain	SGR	FC R	GCE	PER
T_0	12.27	16.29	4.017	32.711	0.472	6.22	0.161	0.163
T_1	12.29	17.33	5.040	41.020	0.573	5.10	0.196	0.235
T_2	12.32	19.06	6.737	54.666	0.727	4.06	0.246	0.276
T_3	12.29	18.07	5.787	47.7110	0.643	4.56	0.220	0.264
T_4	12.28	19.69	7.417	60.076	0.784	3.76	0.266	0.322

Mean value in the same column sharing different superscripts are significantly different (P<0.05)

among neighboring amino acids in protein. The intestinal protease activity was higher than hepatic protease. This was in agreement with the result of earlier scientist (Kumar et al 2007, Bishnoi et al 2017). Due to the supplementation of vegetable oils, the protease activity in experimental treatments was significantly higher than that in T_0 (Table 3). The highest (0.289) protease activity was in T_4 and minimum in T_0 (0.202). In the present study, the supplementation of vegetable oil (@10 per cent in fish diet enhanced the activity of protease. Kumar et al (2007) also observed similar protease profile in different carp species. The improve activity of amylase was also observed in the present study, the minimum and maximum amylase activity was in treatment T_0 (4.6) and T_4 (4.09). Similar findings was found by (Ojha et al 2014, Bishnoi et al 2017).

CONCLUSION

The application of soybean oil in carp diet is most suitable because comparatively higher growth performance, improved growth parameters, proximate composition and digestive enzyme activities were recorded in soybean oil. Thus it is recommended that the use of soybean oil @10 per cent in fish diet for better growth. However, further field studies on different species and testing of different levels are also recommended.

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Comparative Growth of Different Catfish and Carps under Sewage Treated Water

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***Abstract*:** Achieving an environmentally stable and sustainable future of fisheries sector requires the conservation of natural resources and biodiversity. Based on growth parameters, suitability of sewage treated water for different catfish and carps were determined. Four different type of fish species; advance fingerlings of *Pangasius hypopthalamus*, *Catla catla*, fry of *Cyprinus carpio haematopterus* and fingerlings of *Clarias batrachus* were cultured in sewage treated water and freshwater. The weight of catfishes (*P. hypopthalamus* and *C. batrachus*) reared in sewage treated water showed significant increment from 3.64 g and 1.86 g to 9.71 g and 6.21 g within 30 days of experimental period. Similarly, length of fish increased from 8.17 cm and 6.46 cm to 11.85 cm and 8.71 cm. Sewage treated water provides essential nutrients, organic matter, microorganisms that assures the growth of living and non-living food organism for better growth and survival of aquatic animals under aquatic environment, even in the absence of supplementary feeding. However, carps (*C. carpio haematopterus* and *C. catla*) were not able to grow well in the sewage treated water under in vitro conditions. The weight and length of both the fishes declined within 30 days. Additionally, the fry of *C. carpio haematopterus* released in sewage treated water was not able to survive in spite of feeding as the mortality (50%) recorded at 15th day increased to 100 % at 30th day. The growth (weight, length) of catfishes showed significant positive correlation with various water quality parameters as compared to that of the carps.

***Keywords*:** Growth, Catfishes, Carps, Treated sewage water, Water quality

There has been an ongoing practice of utilizing waste products as nutrients in fish ponds since middle ages. Many countries have used treated wastewater for aquaculture as an environmentally friendly resource including Germany (Prein et al 1990), Hungary (Etnier and Guterstam 1996), India (Roy et al 2011), USA (Cuevas-Uribe and Mims 2014) and China (Phong Lan et al 2007). Even in the absence of supplementary feeding, sewage treated water provides essential nutrients, organic matter, and microbes vital for the growth of living and non-living food organisms and therefore, leading to better growth and survival of aquatic organism. By utilizing nitrogen, phosphorous and carbon, algae and phytoplankton grow rapidly. They consume nutrients, bacteria and produce oxygen. A higher oxygen level in the water allows fish to survive and consume algae and phytoplankton (Vansintjan 2021). With the use of treated waste water, existing aquaculture operations can reduce both freshwater demand and water costs, thus increasing profitability. An important key factor in utilizing sewage effectively in fish culture is the choice of fish species. Air breathing fish species like *Clarias batrachus*, *Heteropneustes fossilis*, *Channa* spp., *Pangasius hypophthalmus, Oreochromis mossambicus* and *Ctenopharyngodon idella* can be considered for culture in sewage treated ponds due to their ability to survive in water with low dissolved oxygen content (Samiksha 2019). In addition to a faster growth rate, catfishes can tolerate a wide range of water quality conditions and dense population. Carps being sensitive to lesser dissolved oxygen content cannot survive in sewage treated water. Nevertheless, different species of carps grow at varying rates in sewage-fed ponds. Mandal et al (2021) cultured carps species namely bata (*Labeo bata*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) in different sewage concentration to test their survivability. To investigate the growth evaluation of different catfish and carps under sewage treated water, the present study was conducted.

MATERIAL AND METHODS

To conduct the present study, sewage treated water was collected from sewage treated ponds of the university and brought to the water quality laboratory of College of Fisheries Science, CCSHAU, Hisar. Filtration was done before filling the tanks to ensure that twigs and debris were removed and aerators were installed to ensure adequate oxygen availability. Four fish species were procured from fish farmers to conduct the experiments. At the time of procurement, the weight and length of advance fingerling of *Pangasius*

hypophthalmus, Catla catla, fry of *Cyprinus carpio haematopterus* and fingerling of *Clarias batrachus* were recorded. The fry, fingerlings and fishes were acclimatized for ten days at room temperature before the experimental setup. The fishes were fed with commercially available pellet feed at 6 % of their body weight twice a day.

Fish species	Stage	Weight	Length
Pangasius hypophthalmus	Advance fingerling	1.76 to 6.1 g	6.20 to 10.10 cm
Catla catla	Fish	8.60 to 19.19 g	8.60 to 13.00 cm
Cyprinus carpio haematopterus	Fry	0.22 to 0.52 g	2.30 to 3.90 cm
Clarias batrachus	Fingerling	0.84 to 3.10 g	5.00 to 7.70 cm

All the fish species were cultured in sewage treated water under triplicate conditions to see the effect on weight, length, 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 (%). The fishes were fed at the rate of 8 % of their body weight twice a day. Before setting up the experiment, water quality parameters were estimated following standard methodology.

Statistical analysis: For the statistical evaluation of the study, OPSTAT was used.

RESULTS AND DISCUSSION

Pangasius hypophthalmus: *P. hypophthalmus* cultured in sewage treated water, all growth parameters increased significantly (Table 1). Survivability of the fish was 100 % during the whole treatment. The weight of the fish increased significantly from 3.61 g to 9.71 g as observation days increased from 0 to 30. The fish weight at 10^{th} (5.82 g) and 20^{th} (6.91 g) day were statistically at par with each other. Throughout the study period, the fish length increased significantly at different intervals (Table 3). Furthermore, weight gain, average daily weight gain, percent increment in weight, percent increment in length, biomass and specific growth rate increased continuously. The average weight gain attained the highest value on the 30^{th} day of the study period. The maximum feed conversion ratio was between days 10 and 20. Nile tilapia fed with the sewage sludge showed the best feed conversion ratio (3.18) compared to silver carp and common carp (Abdelhamid et al 2014). Liney et al (2006) reported that after 3 months of rearing in 80 % secondary treated waste water. *Rutilus rutilus* showed significantly greater post-hatch sizes than fish reared in tap water or in 40 % treated waste water. The growth performance was significantly higher for fishes cultured in sewage treated water as represented in our study on *P. hypophthalmus*.

The substantial changes in physicochemical parameters of water causes stress to the fish, thereby, adversely affecting its physiology. The correlation between *P. hypophthalmus* growth parameters (weight and length) and water quality parameters of sewage treated water are presented in Table 2. The weight and length of *P. hypophthalmus* showed significant positive correlation with temperature (0.96), conductivity (0.99) and salinity (0.95) of sewage treated water. The sewage-treated water was have temperature range between 23 and 24.9°C. Similar range of water temperature i.e. 20 to 30°C in the ponds was reported by Bhatnagar and Devi (2013). The optimal water temperatures are 28 to 30°C within which maximal growth rate, efficient food conversion, best condition of fish, resistance to disease and tolerance of toxins (metabolites and pollutants) (Suman et al 2017). The pH ranged from 7.0 to 8.4 which is ideal for fish culture as reported earlier by Santhosh and Singh (2007). The increase in weight (3.92 g to 16.73 g) and length of fish with the increase in water salinity up to 10 % salinity was recorded by Kang'ombe and Brown (2008). In sewage treated water, ammonia and nitrite are not significantly correlated with weight, and there is no significant correlation between length and alkalinity, nitrite, or ammonia in the water. The total dissolved solids (0.94), dissolved oxygen (0.61) and hardness (0.90) of sewage treated water was positively correlated with *P. hypophthalmus* weight and length.

Cyprinus carpio haematopterus: In *Cyprinus carpio haematopterus* (Amur carp) fry fish weigh at 0^{th} day was 0.40g was significantly decreased to 0.35g at 15^{th} day and

Table 1. Growth parameters of *Pangasius hypophthalmus* in sewage treated water 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 (%)	Survivability (%)
0	3.61	8.17					72.88	58.20			100.00
10	5.82[a]	9.68	44.32	0.21	59.77	18.45	116.45	93.10	1.31	2.04	100.00
20	6.91[a]	10.58	66.04	0.10	89.57	29.46	138.17	110.40	4.28	1.39	100.00
30	9.71	11.85	122.06	0.28	166.43	44.94	194.20	155.20	1.97	1.42	100.00

Values denoted by similar letter do not differ significantly with each other

0.21 g at 30th day (Table 3). The fry released in sewage treated water was not able to survive even when the feed was provided. Fish mortality (50%) was at 15th day which increased to 100 % mortality at 30th day. Duration-wise no significant effect of treatment was recorded on fish length, i.e., 3.21, 3.22 and 2.96 cm after 0th, 15th and 30th day, respectively. But due to fry mortality, there was decrease in number of live fish in sewage treated water, hence, average length showed decreasing trend at 15th and 30th day. Kumar *et al.* (2019) observed that Amur carp showed highest growth as compared to catla and rohu in pond integrated with poultry. Sakalli et al (2018) exposed common carps to pond that receive water from sewage treatment part effluents for 360 days under natural conditions. Fish from the exposed pond had different compositions of fatty acids (FA) than those from the control pond. The concentration of 18:1 n-9 and 18:2 n-6 were significantly elevated FA and the longer chain 20:5, 22:5 and 22:6 significantly lowered FA. The reason for mortality in this study may be due to age factor where adults may survive in treated water as reported by Sakalli et al (2018).

Clarias batrachus: Monthly observations on the growth parameters of *C. batrahus* (Desi Magur) in sewage treated water with feed in triplicate condition revealed that there was significant increase in the weight of fish at each observation period (Table 4). Maximum weight was d at 30th day (6.46 g) as compared to 0th day (1.86 g). The water quality of sewage treated water significantly favoured the *C. batrachus* growth. Similarly the length also showed significant increase with increase in observation period and was 6.21 cm at 0th day which significantly increased to 8.71 at 30th day (Table 4). Correlation between weight, length of *C. batrachus* and temperature, conductivity, total dissolved solids, salinity, dissolved oxygen and ammonia were significantly positive (Table 4). The significant negative correlation was recorded with pH and alkalinity whereas nitrite content did not show any correlation with *C. batrachus* growth parameters. In the present study, there was significant increase in the weight and length of C. *batrachus* in sewage treated water. Fingerlings cultured in 100 % treated waste water exhibited elevated growth (720.7 g) compared to the control fingerlings (412.9 g), which were cultured in a commercial pond over a 29-week period. In another study, *C. angullaris* growth was significantly higher in the treated domestic sewage as compared with fish growth in untreated and control set ups (Nwabueze 2013).

Catla catla: There was significant decrease in the fish weight of *C. catla* being 10.48 g at 0th day which decreased to 9.84 g at 30th day; both values being statistically at par with each other (Table 5). After this stage, 50 % mortality in fishes was recorded. The length of fishes at 0th day (10.01cm) and 30th day (10.02 cm) were statistically comparable. The correlation between weight, length of C. *catla* and water quality parameters indicated water temperature, conductivity, salinity, nitrite, ammonia, hardness and alkalinity, showed significant negative correlation with weight and length of C. *catla*, respectively. Total dissolved solids showed positive correlation and pH remained constant during the study period. The C. *catla* in sewage treated water during present study showed that there was a significant decrease in the growth performance due to lower survivability of fish in

Table 3. Effect of sewage treated water on weight and length of *Cyprinus carpio haematopterus* fry at different durations

Observation days	*Cyprinus carpio haematopterus* fry	
	Weight (g)	Length (cm)
0	0.40	3.21
15	0.35*	3.22*
30	0.21**	2.96**
Mean	0.32	3.13

*50% mortality; **100% mortality

Table 2. Correlation between weight of *Pangasius hypophthalmus* 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	3.64	8.17	23.00	2.02	565.00	0.99	4.50	7.60	0.01	0.01	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
Mean	6.52	10.07	24.18	2.08	535.5	1.13	4.25	7.7	1.23	0.16	239	180
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%

Table 4. Effect of sewage treated water on weight and length of *Clarias batrachus* fingerlings at different durations

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 (ppm)	Alkalinity (mg/L)
0	1.86	6.21	24.70	2.32	2.27	1.23	5.50	8.40	0.02	0.05	280.00	114.00
30	6.46	8.71	26.18	2.55	2.79	1.40	5.50	8.40	0.04	0.05	295.00	113.00
Mean	4.16	7.46	25.4	2.43	2.53	1.31	5.5	8.4	0.03	0.05	287.5	113.5
Correlation with weight			0.93	0.98	0.92	1.00	0.87	-0.87	0.87	#N/A	0.98	-0.93
Correlation with length			0.91	0.94	0.94	0.98	0.81	-0.85	0.89	#N/A	0.92	-0.90

Table 5. Effect of sewage treated water on weight and length of *Catla catla* at different durations

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	10.48	10.01	25.90	7.25	3.62	4.07	3.50	8.40	0.30	0.03	430.00	100.00
30	9.84	10.02	26.10	7.55	2.79	4.20	4.00	8.40	0.50	0.05	450.00	125.00
Mean	10.16	10.01	26	7.4	3.20	4.13	3.75	8.4	0.4	0.04	440	112.5
Correlation with weight			-0.92	-0.92	0.92	-0.96	-0.40[1]		-0.60	-0.96	-0.92	-0.90
Correlation with length			-0.86	-0.87	0.86	-0.92	-0.50[1]		-0.50[1]	-0.92	-0.86	-0.84

* 50% mortality, [1] Non-significant at 5%

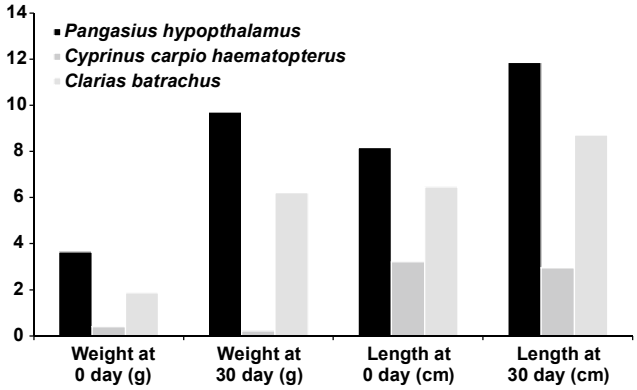

Fig. 1. Comparative evaluation of growth of experimental fishes in sewage treated water

sewage treated water. Carps, being very sensitive to low dissolved oxygen content, were not able to survive in sewage tanks. Dasgupta et al (2008) observed better growth of carps in diluted sewage water than raw sewage water. Nwabueze (2013) reported an increasing sequence of length in 100% < 25% < 75% < 50% concentrations and increasing sequence of weight in 25% <100% <75% <50% concentrations of sewage. Jana et al (2016) recorded highest growth of *L. rohita* at 75 % concentration of sewage than other treatments. Vijaykumar et al (2020) also reported highest specific growth rate of *Catla* in the ponds integrated with poultry farm followed by Amur carp and Rohu.

CONCLUSION

The depiction of growth parameters of the four experimental fishes indicated that catfishes (*P. hypopthalamus* and *C. batrachus*) are suitable for culture in sewage treated water in terms of growth parameters and survival. The length and weight of P. *hypopthalamus* and C. *batrachus* increased within 30 days. However, carps reared in sewage treated water, i.e., *C. carpio haematopterus* and *C. catla* were not able to grow in sewage treated water under *in vitro* conditions. The weight and length of both the fishes decreased within a time period of 30 days. Additionally, the survived fish species i.e. *P. hypopthalamus*, *C. batrachus* were successfully cultured for an extended period of 90 and 60 days respectively.

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Geo-informatics Approach for Sustainable Aquaculture Expansion: A Case Study on Mapping the Availability of Water Spread Area and Fish Production Potential in Manar Reservoir, Maharashtra

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***Abstract*:** To utilize the Indian reservoir's untapped fish production potential, managers require precise information about the water body. The current study employed Normalized Difference Water Index (NDWI) to generate reservoir's Water Spread Area (WSA), Water Presence Frequency (WPF) and the Digital Elevation Model for bathymetry analysis. The reservoir has a total area of 2490.86 ha and retained approximately 90 percent and 69 percent of its maximum WSA in February and May, respectively. According to the estimated WSA, stocking ~10 lakh fish fingerlings can yield around 200 mt of fish production. The reservoir has a large area with high WPF (63.70% in pre-monsoon and 87.79% in post-monsoon season) and around 32 percent of the reservoir retains water throughout the year. The majority of the reservoir area falls in the range of 4 to 10-meter depth still the reservoir failed to meet the minimum depth criteria for the cage culture set by the National Fisheries Development Board. Therefore, it has been determined that cage culture cannot be practiced in this reservoir, however, fish production can be increased by stocking pen-reared fingerlings in potential reservoir sites by erecting pens.

***Keywords*:** Reservoir, Normalized difference water index, Water presence frequency, Water spread area, Bathymetry mapping, Geo-informatics

Fisheries and aquaculture play an important role in the food supply, food security, and income generation. They account for ~20 percent of per capita animal protein intake for more than 1.5 billion people and provide employment to ~200 million people (Cochrane et al 2009). Indian fishery is changing its dominance from marine to inland with a 76% contribution from the latter to the total fish production. Within inland fisheries, a shift from capture to culture- based fisheries has paved the way for a sustained blue economy. (DoF 2020, 2022). Despite the significant growth of inland fisheries, the potential is yet to be realized, therefore, more emphasis is being placed on the existing underutilized natural waterbodies like reservoirs, lakes, tanks, etc. to maximize their productivity potential than that on farm-based aquaculture (Anand et al 2020, Yadav et al 2021). Because of its tremendous scope of fish production, reservoirs are named as 'Sleeping Giants'. PMMSY is targeting to harness the underutilized potential of the reservoirs and the department is committed to installing 20,000 cages in the reservoirs and water bodies which in turn would produce an additional 60,000 mt of fish by 2025 (DoF, 2022).

Maharashtra ranks 7th with ~5 percent share in the country's fish production and is yet to explore its untapped potential (Bhendarkar et al 2020). It is having the second highest number of medium and large reservoirs (No. 81) followed by Gujarat (No. 88) (DoF 2022). The total water area of reservoir and lake under the DoF Maharashtra is 2.82 lakh ha with an anticipated fish production of 1.28 Lakh MT (DoF 2021). Manar is one of the medium reservoirs of Maharashtra and has a significant share in the fish production of the state. Although the reservoir has been stocked with fingerlings, there is still a yield gap. The resultant gap in the expected and the actual production can be due to the higher mortality rate which can be lowered by stocking bigger sized fingerlings. Water resource structures require careful planning to ensure that water management objectives are met (Dumka and Kumar 2021). The present study assesses the seasonal water dynamics and depth of the Manar reservoir with the help of retrieved Water Spread Area and bathymetry estimation using Remote Sensing (RS) and Geographical Information System (GIS) techniques. The study also attempts to identify the potential site for enclosure culture fisheries.

MATERIAL AND METHODS

Study area: Manar is a medium reservoir (18°50'N to 18°51'N latitudes, 77°19' to 77°09'E longitude) located at village Warwant, Maharashtra (India). Manar Dam project has been

completed in 1968 with the primary services of irrigation and small-scale fisheries. The reservoir contract has been given to the Jalkranti Fishermen Cooperative Society Limited, Bahadarpura for the years 2019 to 2023. This reservoir was chosen for the study because of its large Water Spread Area (WSA) and good water holding capacity throughout the year. Given the availability of water and current fish production, it has been hypothesized that enclosure culture can increase fish production. Spatio-temporal change in WSA, Water Presence Frequency (WPF) of the Manar reservoir were monitored for the period 2019 to 2022. Availability of water extent was considered based on irrigation in nearby area. February (Rabi season) was considered for water availability for at least 8 months and May was considered for water availability for at least 11 months. It was assumed to be the minimum water extent throughout the year.

Satellite data acquisition: For the present study, Sentinel-2 Multispectral Instrument (MSI) satellite data from 2019 to 2022 was obtained from the open access Copernicus Hub. In image analysis, band-3 (green band) and band-8 (near infrared band) were used with the spatial resolution of 10 m. For estimating reservoir water spread dynamics, a total of 16 images were processed, i.e., 2 images each for February and May over the four-year study period. WPF estimation was performed using 64 images, implying that a total of 8 months were studied (June, July, August and September excluded due to high cloud cover in satellite images). Figure 1 shows diagrammatic representation of the methodological framework adopted for WSA and WPF assessment.

Waterbody boundary formation: The reservoir outer boundary shapefile was created in Quantum GIS (QGIS). Sentinel 2 MSI image from November 13, 2019, was used for this purpose. The farthest water mark of a waterbody visible as tonal discontinuity of wet areas from the bordering dry area was used to define the outer boundary of a waterbody (Anand et al 2020).

Water body extraction: Water indices such as Normalized Difference Water Index (NDWI) (McFeeters 1996) differentiates between the water, soil and terrestrial features. NDWI is basically used to delineate and monitor changes in surface water and can be calculated using the green band and near infrared (Eq. 1).

$$NDWI = \frac{G - NIR}{G + NIR} \qquad \text{(Eq. 1)}$$

where, G is green and NIR is near infrared channel named as band-3 and band-8, respectively in the sentinel 2 dataset. In QGIS, NDWI was calculated using the raster calculator tool and clipped with the reservoir outer boundary vector shape file to extract only reservoir information. NDWI value ranges between -1 to +1 where the values between -1 to 0 represents the soil and terrestrial feature (non-water area) and 0 to +1 represents the water feature. These values of the pixels were threshold manually by comparing with the true colour composite image with the NDWI product and the NDWI product's values of water (1) and non-water (0) pixel.

Assessing the water spread dynamics: Considering the annual rainfall fluctuation and changing pattern of water usage, WSA of four subsequent years (2019-2022) were studied for the true representation of water spread dynamics of the reservoir. Classified image of WSA derived from NDWI for February (8 months) for four succeeding years were aggregated into a single February composite map. Similarly, single water availability layer was prepared for May (11 month). Area of both the maps were calculated using the attribute table.

Composite seasonal WSA map: Aggregate maps of February and May were integrated and one final composite map was generated for WSA. The two aggregate bit map images were first converted into vector shape files and then merged in QGIS using the union tool. The polygon in the

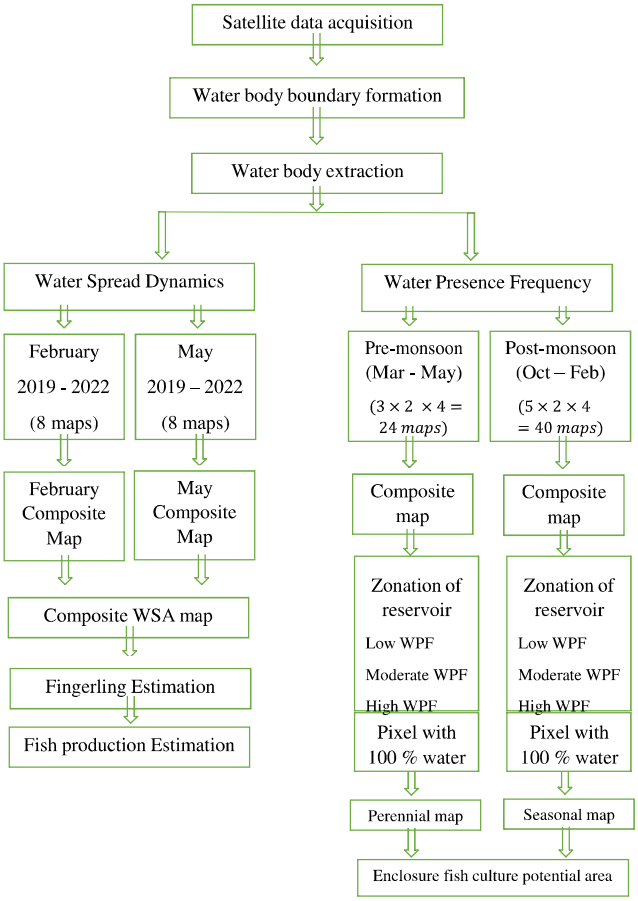

Fig. 1. Diagram of the methodological framework used in this study

composite layer was divided into three zones (Anand et al 2020):

1. Dry bed zone/zone with less than 8 months of water availability
2. 8-month water availability zone from June/July to February/March
3. 11-month zone that retains water from June/July through May

Estimating fingerlings requirement and minimum fish yield potential from seasonal WSA: Number of fingerlings required for stocking in water availability zone was calculated using the following Eq. 2.

$$F = a \times SD \quad \text{(Eq. 2)}$$

where, F, the average minimum fingerling required per year; *a*, the average WSA, SD, the minimum stocking density suggested by the Government.

The average WSA means average of February (8 months) and May (11 months). i.e., here, average WSA of February and May was considered to eliminate the risk of overstocking (if area for February was considered) or understocking (if the area of only May was considered).

Minimum fish yield production potential was calculated using the following Eq. 3.

$$Y = F \times AW \times SR \text{ (Eq. 3)}$$

where, Y, potential fish yield from the reservoir; F, estimated number of fish fingerlings to be stocked; AW, average body weight of individual fish; SR, survival rate

Assessment of seasonal WPF: WPF was estimated using the following Eq. 4 (Anand et al 2020). The reclassified NDWI images were integrated in pre-monsoon and post-monsoon bit maps.

$$WPFj = \frac{\Sigma^{n}_{i=1} I_j}{n} \times 100 \quad \text{(Eq. 4)}$$

where WPFj, WPF of jth pixels in a time period; Ij, jth pixel having water in the selected NDWI images; n, number of images.

The values of WPF ranges between 0 to 100%, as these values approaches to 100% the frequency of the water presence in the pixels increases, lower values indicate less frequent water appearance in the pixel. Based on these values of the WPF, the map was classified in three classes as low (WPF, 0-33%), moderate (WPF, 33 – 66%) and high (WPF, 66 -100%), pixels with 0% WPF were classified as no water area (dry beds).

Potential area estimation for enclosure culture: The WSA of the reservoir was divided into two parts namely, seasonal and perennial area.

Perennial area: The perennial area is the area of the reservoir where the WPF was 100% in the pre-monsoon season, i.e. this is the area where the water will be present almost year-round (11 months). Pixels with 100% WPF in the pre-monsoon composite map were recorded to generate a perennial area map.

Seasonal area: Pixels with 100% WPF in the post-monsoon composite map were recorded to generate the seasonal WSA map.

Reservoir bathymetry assessment: For the establishment of the enclosure culture in the reservoir, one more important criterion should be considered is the depth of the reservoir. In the present study, depth of the reservoir was estimated using DEM through these steps:

Generation of path map: Using Latitude and Longitude Path map of the reservoir prepared in Google Earth Pro

Generation of elevation map: Elevation data has been generated on the open access GPS Visualizer website using the path map

Interpolation: Interpolation is a statistical method by which related known values are used to estimate an unknown value or set of values. There are various methods of interpolation from which Kriging was used for the study because of its superiority over other methods (Khattab et al 2017)

Clipping the reservoir area: Water area of the reservoir has been clipped using the shape file of the full reservoir (maximum water availability zone)

Classification: Based on the elevation of the given sample points, reservoir depth was classified at 2 m depth interval

Water column measurement for the seasonal and perennial water area: Using the coastal boundaries water column range were estimated for the seasonal and perennial waters.

RESULTS AND DISCUSSION

Seasonal water availability in the reservoir: Using NDWI, the available WSA of the reservoir was studied for February and May (Table 1). The maximum WSA of the Manar reservoir was 2490.86 ha, average WSA in February and May (2019-2022) was 2250.41 ha and 1740.9 ha, respectively (Fig. 2). This shows that the reservoir is holding a huge amount of water throughout the year i.e., around 90 percent till February and 69 percent till May.

Estimation of fingerlings requirement: In case of small and medium reservoirs, auto- stocking is not possible. For better utilization of the waterbody, regular stocking of the hatchery-reared fish seeds is required. The National

Table 1. Seasonal WSA of the reservoir

WSA	Post-monsoon	February	May
In hectares (ha.)	2490.86	2250.41	1740.19
In percentage (%)	100%	90.34%	69.86%

Fisheries Development Board (NFDB) proposes reservoir stocking at a standard stocking rate of 1000 fingerlings but implementing agencies can alter the stocking rate based on size of the reservoir, water retention capacity, prevalence of predators and productive water area. The medium and large reservoirs should be stocked with a minimum of 500 fingerlings per hectare (NFDB, 2014). Considering the minimum stocking density suggested by the NFDB, estimated minimum number of fingerlings needed for effective waterbody utilization is around 10 lakhs (Table 2).

Estimation of fish production potential: Fish production depends on several limnological, hydrobiological ad climatic features of the waterbody (Pal & Yadav 2022). This governing feature differs in every water body and that affects production potential of the water body. For the calculation of potential fish production, a 10% survival rate is considered with average weight of fish as 2kg (Anand et al 2020). Estimated fish production potential is around 200 mt (Table 3).

Seasonal WPF: WSA and the water storage capacity of the waterbody can be correlated with sediment deposition and the natural sedimentation process is changing due to several human activities (Kummu et al 2010, Pandey et al 2016) therefore, it is necessary to estimate WPF of the reservoir

Table 2. Estimated fingerling requirement for the reservoir

Month	Area of water availability zone (ha)	Stocking density (SD) (nos./ha)	No. of fingerlings required (F)
Feb	2250.41	500	1,125,205
May	1740.19	500	870,095
Average	1995.3	500	997,650

Table 3. Estimated fish production potential

Month	Fingerlings required	Potential yield (mt)
Feb	1,125,205	225.041
May	870,095	174.02
Average	997,650	199.53

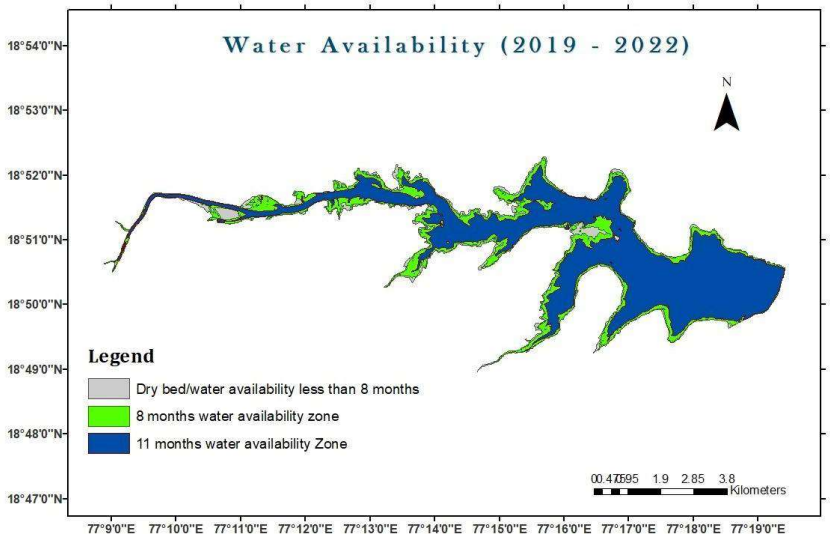

Fig. 2. Seasonal WSA of the reservoir

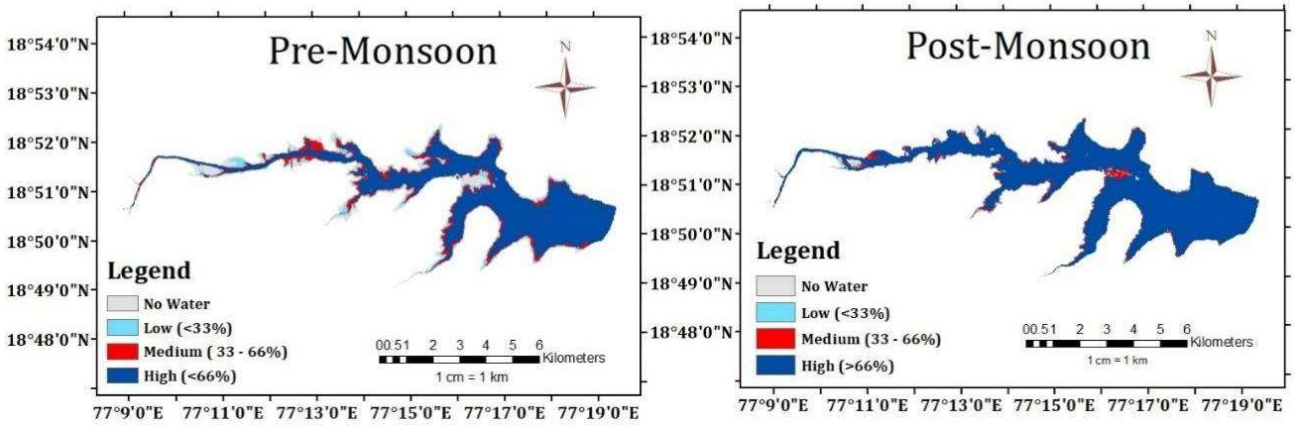

Fig. 3. Seasonal and perennial WPF map

Table 4. Seasonal and perennial WPF map

WPF	Post-Monsoon (October-February)		Pre-Monsoon (March-May)	
	Area (ha)	% of total	Area (ha)	% of total
No Water Zone	34.8405	1.39%	316.714	12.55%
<33%	102.258	4.10%	280.12	11.24%
33-66%	165.312	6.63%	305.95	12.24%
>66%	2186.72	87.79%	1586.89	63.70%
TOTAL	2490.86	100%	2490.86	100%

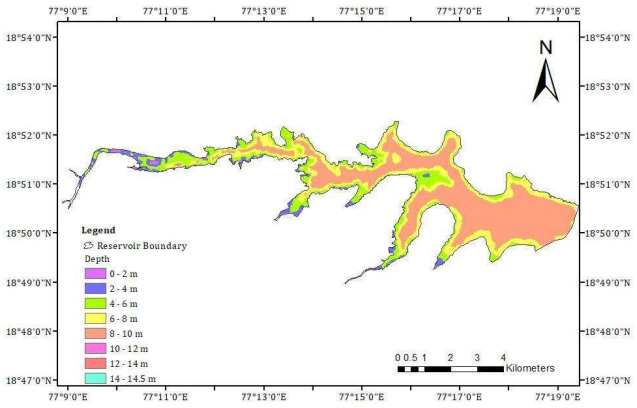

Fig. 4. Post-monsoon bathymetry map of the reservoir

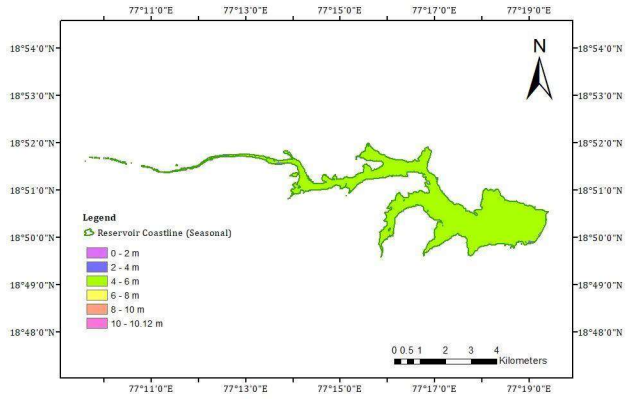

Fig. 5. Seasonal area bathymetry map of the reservoir

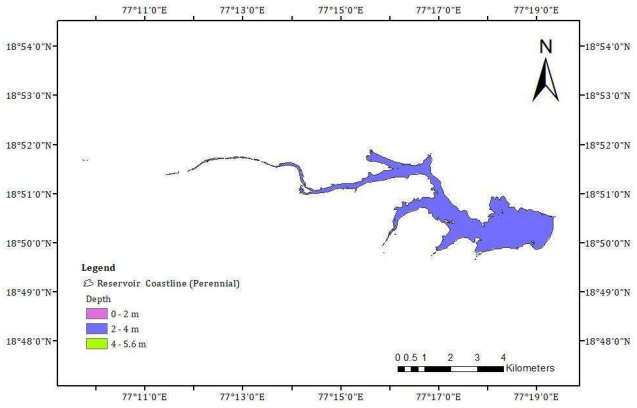

Fig. 6. Perennial area Bathymetry map of the reservoir

Table 5. Seasonal and perennial WSA

Reservoir	Category	Area (ha)	%
Manar Reservoir (2490.86 Ha)	Seasonal area	1192.55	47.87%
	Perennial area	820.789	32.95%

before setting up any fish culture activity in the reservoir (Table 4 , 5). Approximately 87.8 and 63.7% of the reservoir area is showing high water presence in the post-monsoon and pre-monsoon seasons respectively. The study reveals that the reservoir is retaining a good amount of water (32%) throughout the year. WPF map of the reservoir during pre-monsoon and post-monsoon shows the area of the reservoir having potential for the enclosure culture based on the WPF (Fig. 3).

Reservoir bathymetry assessment: From the bathymetry analysis, in the post-monsoon season, the deepest point of the reservoir is having a depth of 14.5 m, but majority of the reservoir area is falling in the range of 4-10 m depth (Fig. 4). The seasonal and perennial WSAs have the majority water depth in the range of 4-6 m and 2-4 m, respectively (Figs. 5, 6). Permanent cage culture cannot be established in Manar reservoir as the requirement of at least 10 m water depth (as per NFDB) has not been met. Fish production of the reservoir can be enhanced by stocking bigger sized fingerlings, study has depicted a 12.6% increase in fish yield by raising smaller fingerlings in pens and releasing them into a beel (Debnath et al 2021). For fingerling rearing, pens can be constructed in the potential reservoir area which retains a good amount of water.

CONCLUSION

The study was conducted to measure the WSA of the reservoir throughout the year and to suggest the required stocking material of seed so that its potential can be adequately utilized. The reservoir is currently being stocked with the minimum stocking density, but the actual production from 2019-2021 is similar to the estimated production. In order to achieve the maximum potential production, stocking can be increased. Cage culture cannot be practiced in the

Manar reservoir because of low depth. However, the production can be increased by increasing stocking density of bigger sized fingerlings to 1000 numbers/ha/year in pen culture. Various studies have accounted for the threats of sedimentation on water storage capacity and sustainability of the reservoir and is proposed to assess reservoir sedimentation in order to determine its impact on the WSA and reservoir depth.

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Estimation of Predatory Bird Damage to Winter Guava Crop

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Abstract: The present study was aimed to record bird community characteristics and extent of damage caused by birds in guava orchard at Haryana Agricultural University, Hisar and village Salemgarh from August, 2019 to January, 2020. Rose-ringed Parakeet was the worst avian pest at both locations. In guava crop, the pestilence at location I was caused by Rose-ringed Parakeet, Alexandrine Parakeet, Red-vented Bulbul, Brown-headed Barbet and Western Koel. At location II, the frugivorous species which inflicted damage to the guava crop were Rose-ringed Parakeet and Red-vented Bulbul. The parakeets preferred both unripe and ripened fruits, while the other species preferred only ripened fruits. Birds other than parakeets thrived only on the pulp and seeds of those fruits that the parakeets had previously consumed. Different effective methods of bird manual scaring were employed at location I and bird damage to guava fruit was 4.92%. Bird manual scaring methods were not implemented on a regular basis at location II, fruit damage was estimated to be 8.91%. There was significant difference in the mean damage fruit yield production of guava crop at location I and II. Therefore, implementation of auditory technique were effective to minimise bird depredatory attacks, reduce economic losses and improve crop quality and yield.

Keywords: Avian pest, Crop loss, Damage estimates, Guava

Agricultural productions are cornerstone of the world economy. The goal of World Health Organization is to increase fruits and vegetables consumption because fruits and vegetables have such a tremendous positive influence on human health. As a result, expanding fruit production offers both social and economic advantages (Lindell et al 2016, Balkrishna et al 2022). *Psidium guajava L*. (Guava) is India's fifth most significant commercial fruit crop after *Mangifera indica, Musa* sp., *Citrus* sp. and *Vitis vinifera*. Being inexpensive and widely accessible, guava is common fruit in India and it is widely cultivated and commercialised (Sharma 2020, Santhosh kumar et al 2022). Its cultivation has become a very profitable agricultural enterprise in India. Insects and birds are two significant factors contributing to a decrease in agricultural output. Bird pests are regarded as a potential threat to agriculture since they devour a wide range of crops, from fruits to cereals (Brady 2022). Agricultural bird pest are as ancient as agriculture itself, both in India and across the world. Of the world's 8650 bird species about 1,200 are found in the Indian subcontinent, representing 20 orders (Rana and Narang 2004, Sausse and Levy 2021). In India, 2.1% birds species have been documented to cause agricultural damage primarily to fruit-bearing and grain-yielding crops (Schackermann et al 2014, Kiran et al 2022). Damaged fruits can be susceptible to infection by microorganisms and lower the quality as well as quantity of fruit (Steensma et al 2016, Mirzazadeh et al 2021). The problem is that birds damage more fruit than they consume, rendering hanging fruit unsuitable for market and causing premature ripening, resulting in inferior commodities being supplied (Elser et al 2019). The percentage of damage may vary in different crops e.g. small berry production is estimated to be damaged by 30 to 35%, wine and table grapes by 7%, apples and pears by 13%, stone fruits by 16 % and nut crops by 22 % (Imarohi 2014). Numerous bird species are the most pestiferous species, inflicting damage to crops in different seasons depending on environmental circumstances such as the accessibility of alternative food sources because of drought and cold (Elser et al 2019). To reduce bird damage, knowledge about the bird species abundance in a specific area and crop is essential because assemblage of birds varies according to the area (Luck et al 2015, Sauer et al 2017). Long-term studies on the biology, flocking movement, behaviour and crop-specific information of the main pest species are required to control bird damage. These studies can help to identify which species cause damage and which bird mitigation strategies may be most efficient as species may respond differently to control measures (Hannay et al 2019). Fruit growers have identified bird damage as a serious problem that has received little attention. There has been little research on the economic implications of bird damage to fruit crops, with much of it focusing on wine grapes (Anderson et al 2013). The present studies were therefore, aimed to evaluate the nature and extent of damage caused by birds on winter guava crop.

MATERIAL AND METHODS

Study site: The location of the present study were experimental orchard of HAU (Location I) and village Salemgarh (Location II) situated in the district of Hisar, Haryana, India. Location I lies at latitude of 29°09'17.3"N and longitude of 75°41'28.0" E. Location II lies at latitude of 29°11'18.1"N and longitude of 75°32'39.8"E. To study the pattern and extent of damage by birds, well-maintained orchards with an area of 1acre were selected at both the locations.

Methodology: The study was conducted to assess birds community composition, nature and extent of damage by birds in guava orchard from August, 2019 to January, 2020 at selected locations. The observations were taken on weekly basis from 8.00 to 10.00 A.M. and 4.00 to 6.00 P.M. during the winter season, but harsh weather conditions were avoided in order to minimise the weather-related errors. A Nikon COOLPIX P900 digital camera and Nikon ACULON binoculars (8×42, 8°) were used for photography and observations were recorded from long distances so as not to disturb the normal activity of birds. Bird's species visiting the guava crop were recorded to check whether they were perching on the branches, foraging under tree canopies, roosting or using the standing crop as a cover to avoid aerial predators and feeding on guava fruit. Reference book was used to identify the birds (Ali 2002, Grimmet et al 2016). Details on the nature and extent of fruit damage by birds were noted down. Observations related to avifaunal diversity, richness and relative abundance at the flowering, fruit setting and ripening stage of guava crop were also recorded. Relative abundance was calculated by the given formula:

$$\text{Relative abundance (\%)} = \frac{\text{Total number of individual species}}{\text{Total number of species population}} \times 100$$

The management practices were used to minimise the damage to fruit crops at both locations, but intense auditory techniques (shouts by human beings, beating of empty drums, catapult, and crackers) were used at experimental orchards of HAU as compared to village Salemgarh.

Assessment of guava fruit damage by frugivorous birds: Bird damage to fruits was calculated using the weighing method. Ten trees were selected from the total area, five from the periphery and another five from middle of the orchard. The weight of fruits per tree at the fruit setting and ripening stage was recorded from both the locations. Fruits damaged and dropped by birds were collected, placed in polythene bags and weighed until the research was completed to record total fruit production and depredation by birds. Differences in yield at both the location were used to estimate the percent damage by following formula:

$$\text{\% damage} = \frac{\text{Number of damaged fruits}}{\text{Total numbers of fruits}} \times 100$$

Data analysis: Shannon-Weiner Diversity Index, Simpson's Index of Diversity and Species evenness were calculated using the software PAST version 4.0.

Independent T-test: Independent T-test was carried out to compare the mean damaged production of guava fruits of location I with location II using statistical software SPSS (Version 28.0.1.1(14)).

RESULTS AND DISCUSSION

The present study was conducted to study the avian diversity in different growth stages of guava crop and to assess the damage and evaluation of bird pest management methods.

Species abundance: A total of 32 and 23 bird species were observed at location I during morning and evening hours respectively (Table 1). A total of 17 and 11 bird species were observed at location II during morning and evening hours respectively. Sidhu and Kler (2017) reported 30 bird species belonging to six orders in orchard of guava at Baranhara (Punjab). Diversity and abundance of birds was higher at location I because of mixed cropping system (date, ber, grape, apple, ber, sapota, mulberry, mango and kinnow) as compared to location II (only ber) which ensures abundance and variety of food resources to birds. Round (2000) also observed that mixed-species forest provides plenty of food sources to birds. Genghini et al (2006) also stated that in organic orchards avian community are more diversified. Species richness was 24, 16 and 21 at flowering, fruit setting and ripening stage respectively during morning hours whereas species richness was 19, 10 and 16 at flowering, fruit setting and ripening stage respectively during evening hours at location I. Species richness was low at location II. Avian community composition was recorded maximum during morning hours at flowering and ripening stage at both locations, because flowering stage attracts many insectivorous species like Black drongo and Asian green bee-eater whereas ripening stage provides large quantity of food to birds. Similar kinds of observations were reported by Sidhu and Kler (2018).

Relative abundance at three stages of guava viz flowering, fruit setting and ripening stages revealed that the Rose-ringed Parakeet and Alexandrine Parakeet were the most dominant species at location I and Rose-ringed Parakeet at location II. Kler and Kumar (2015), Arora et al (2023) also reported that Rose-ringed Parakeet is the major pest species inflicting serious damage to guava crop.

Diversity index: Shannon-wiener index for diversity richness showed maximum diversity 2.30 at the flowering

Table 1. Avian community composition at different developmental stages of winter guava crop at location I and II

Crop stage	Flowering stage	Fruit setting stage	Ripening stage	Flowering stage	Fruit setting stage	Ripening stage
	(Aug-Sep)	(Oct-Nov)	(Dec-Jan)	(Aug-Sep)	(Oct-Nov)	(Dec-Jan)
	Morning			Evening		
Bird species	Relative abundance (%)					
Milvus migrans (Black kite)	1.97	-	-	2.01	-	-
Elanus caeruleus (Black-winged kite)	(0.96)	(0.44)	-	-	-	(0.19)
Accipiter badius (Shikra)	(0.48)	(0.44)	-	-	-	-
Ocyceros birostris (Indian grey hornbill)	(0.96)	0.75 (0.87)	0.53 (0.29)	2.35	1.63 (0.67)	0.54 (0.38)
Streptopelia decaocto (Eurasian collared-dove)	-	-	1.33	-	-	1.09
Halcyon smyrnensis (White-breasted kingfisher)	1.18 (0.96)	0.75 (0.87)	0.80 (0.29)	0.67 (0.46)	0.98 (0.67)	0.54 (0.57)
Coracias benghalensis (Indian roller)	(0.48)	-	-	(0.46)	(0.33)	(0.19)
Merops orientalis (Asian green bee-eater)	3.94	-	-	3.36	-	-
Vanellus indicus (Red-wattled lapwing)	6.30 (6.25)	3.36 (12.23)	3.18	1.68 (3.67)	0.65	1.63 (1.14)
Eudynamys scolopaceus (Western koel)	0.79	1.12	1.59 (0.88)	2.01	0.33	1.09
Clamator jacobinus (Jacobin cuckoo)	0.39	-	-	-	-	-
Francolinus pondicerianus (Grey francolin)	-	-	-	2.68	-	-
Gallinula chloropus (Common moorhen)	-	-	0.27	-	-	-
Corvus splendens (House crow)	2.36 (8.65)	2.61 (3.06)	2.39 (3.53)	4.70	-	1.90
Corvus macrorhynchos (Indian Jungle crow)	-	-	0.80	-	-	0.27
Dendrocitta vagabunda (Rufous treepie)	0.79 (0.96)	0.75	1.33 (1.18)	1.34 (0.92)	1.31 (0.67)	0.54 (0.38)
Dicrurus macrocercus (Black drongo)	0.79 (1.44)	0.37	0.53	0.67	-	-
Lonchura punctulata (Scaly breasted munia)	-	-	-	2.01	-	-
Euodice malabarica (Indian silverbill)	0.39	-	0.53	-	-	-
Argya striata (Jungle babbler)	6.30	5.22	10.08	4.36	5.23	5.43
Anthus rufulus (Paddy field pipit)	-	-	-	(0.92)	-	-
Motacilla alba (White wagtail)	-	1.87	1.06	-	-	-
Motacilla flava (Western yellow wagtail)	-	4.10	1.86	-	-	0.82
Phoenicurus ochruros (Black redstart)	-	-	0.53 (0.88)	-	-	0.27
Saxicoloides fulicatus (Indian robin)	-	-	0.27	-	-	-
Cinnyris asiaticus (Purple sunbird)	0.39 (0.96)	-	-	0.34 (0.46)	-	-
Pycnonotus cafer (Red-vented bulbul)	3.94 (3.37)	2.24 (2.18)	3.98 (3.24)	2.01 (1.83)	1.96 (2.33)	2.17 (3.42)
Gracupica contra (Asian pied starling)	0.79	-	-	3.36	-	-
Acridotheres tristis (Common myna)	7.87 (10.10)	4.48 (7.86)	4.77 (1.47)	4.03	-	1.09
Pastor roseus (Rosy starling)	0.39	-	-			
Ardeola grayii (Indian pond-heron)	0.39	-	-			
Bubulcus ibis (Cattle egret)	5.12	4.48 (3.06)	-			
Threskiornis melanocephalus (Black-headed ibis)	1.18	-	-			
Pseudibis papillosa (Red-naped ibis)	1.97 (7.21)	-	(1.76)	(5.96)	-	-
Psilopogon zeylanicus (Brown-headed barbet)	1.97	1.49	2.39	1.01	1.31	1.36
Dinopium benghalense (Black-rumped flameback)	0.79	-	-			
Palaeornis eupatria (Alexandrine parakeet)	9.05	14.18	15.65	16.44	25.82	24.46
Alexandrinus krameri (Rose-ringed parakeet)	40.94 (57.21)	52.24 (69.00)	46.15 (86.47)	44.97 (85.32)	60.78 (95.33)	56.79 (93.73)
Species richness	24 (14)	16 (10)	21 (10)	19 (9)	10 (6)	16 (8)

Without bracket - Location I, Bracket ( ) - Location II

stage in location I during morning hours and lowest (0.26) at the fruit setting stage in location II during evening hours (Fig. 2, 3). Species evenness was maximum (0.42) at the flowering stage at location I during morning hours while minimum (0.17) was at ripening stage at location II during evening hours. D, calculated from the location I with its highest value as 0.80 at the flowering stage during morning hours and lowest value as 0.09 at fruit setting stage during

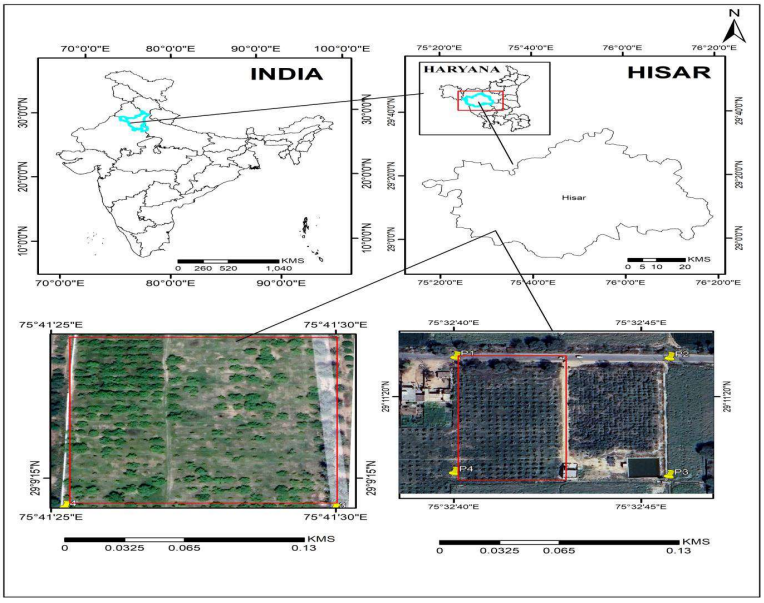

Fig. 1. Location map of study site in region Hisar, Haryana

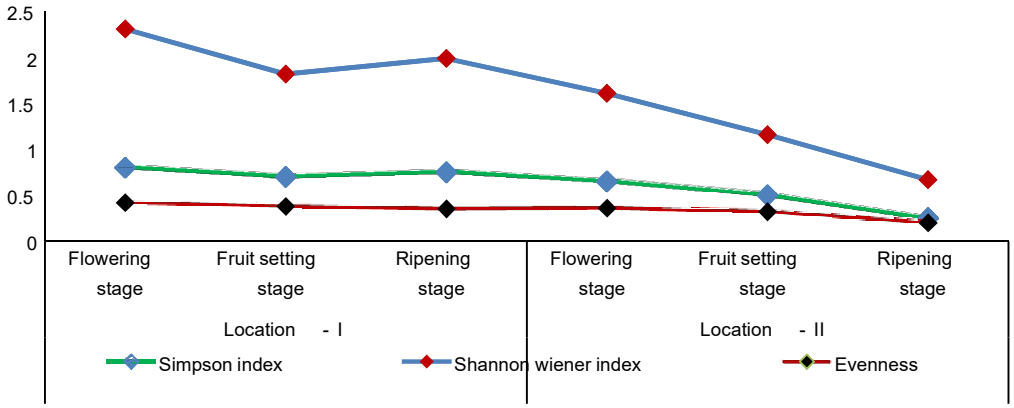

Fig. 2. Diversity indices of avian community at different developmental stages of winter guava crop during morning hours

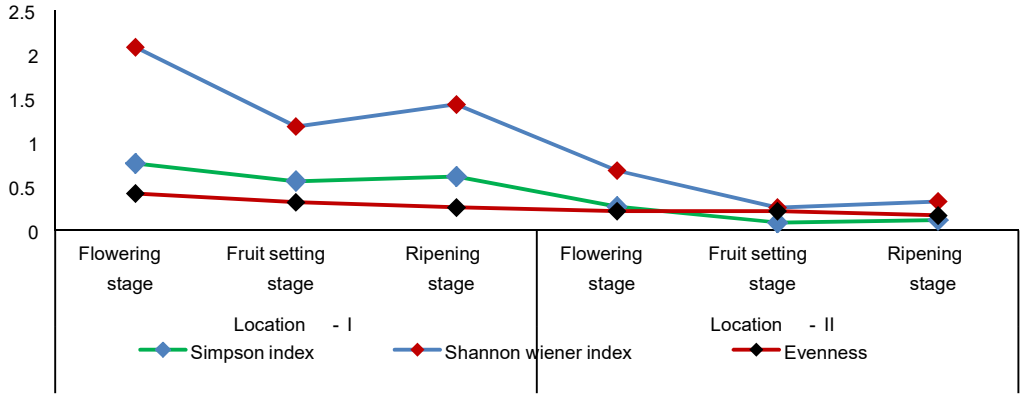

Fig. 3. Diversity indices of avian community at different developmental stages of winter guava crop during evening hours

evening hour from location II. The higher value of species diversity, species evenness and simpson index were recorded at the flowering stage during morning hours. Maximum number of insectivorous species were observed at the flowering stage which was because of the easy availability of insect diversity. The highest species richness and species diversity at different developmental stages of the guava crop recorded at location I as compared to location II could be due to presence of different types of vegetations as well as crops in the surrounding areas at location I whereas, more uniform cropping pattern was observed at location II. The findings are in line with Kaur and Kumar (2022). Rajashekara and Venkatesha (2015) also confirm present findings that the species richness, species diversity and evenness of avian communities vary significantly in different landscapes.

Nature of damage inflicted by frugivorous bird species: Rose-ringed Parakeet, Alexandrine Parakeet, Red-vented Bulbul, Brown headed Barbet, Western Koel and House Crow were the frugivorous bird species inflicting damage to guava fruit at location I (Fig. 4). At location II, the frugivorous species which inflicted damage to guava crop were Rose-ringed Parakeet and Red-vented Bulbul. Kross et al (2012) reported that many bird species, including parakeets and small passerines inflicted economic loss to growers by consuming crops. Rose-ringed Parakeet was the main depredatory bird at location I and location II and inflicted damage to the guava fruits, which led to decrease in the yield of crops and loss to the farmer. The present findings are similar to the observations recorded by Arora et al (2023). House Crow was sighted rarely to cause damage to guava fruit during the study period. Hussain and Vashishat (2021) has also reported that house crow attack the guava fruit and rendered them unfit for the market. A large flock of parakeets were observed hovering above the guava orchard. Rose-ringed Parakeet and Alexandrine Parakeet depredates at both ripen and unripe stages and dropped fruits under the parent tree. Red-vented Bulbul, Brown headed Barbet, Western Koel and House Crow feed on guava fruit at the ripening stage and are pulp gleaners. The pattern of parakeet damage on guava was like triangular marks and deep gouges. Dulera and Nayi (2022) also reported similar pattern of damage on guava fruit. Red-vented Bulbul, Brown-headed Barbet, Western Koel and House Crow peck on the fruit which were already eaten by parakeets. Sometimes it was recorded that parakeet detach the unripe guava from the tree and fly away to the date palm tree which surrounds the guava tree and use one foot to hold the guava for feeding purposes. It was also observed that parakeets fly away to nearby roosting sites after detaching the guava holding the fruit in their beak to feed their young ones. Maximum fruit damage seemed to be related to colour changing state at ripening stage which attracted flocks of Rose-ringed Parakeet. Grasswitz and Fimbers (2013) also observed that as the fruit weight increased at the ripening stage, the extent of damage also increased. The clear correlation was observed between parakeet visits and fruit damage in the orchard. In order to meet their food needs for spending the fasting night in their roost, the damage was observed at a higher rate in the evening as compared to the morning. Similar results have also been described by Manzoor et al (2013).

Assessment of crop damage: Out of 10 sampled trees tested, total fruit yield was 677 kg at location I and total weight of damaged fruit and healthy fruit was 33.35 and 644 kg

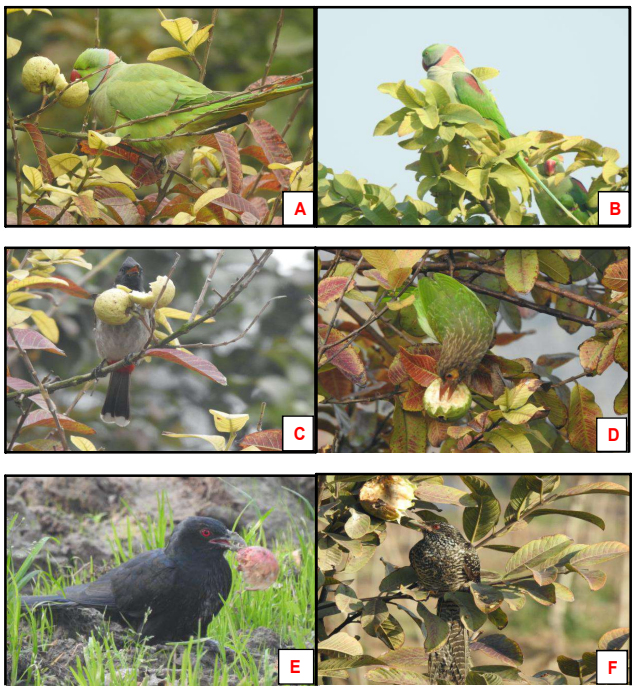

Fig. 4. Frugivorous bird species inflicting damage to guava fruit. A-Rose-ringed Parakeet | B-Alexandrine Parakeet | C- Red-vented Bulbul | D-Brown-headed Barbet | E-Western Koel (Male) | F. Western Koel (Female) © Kiran

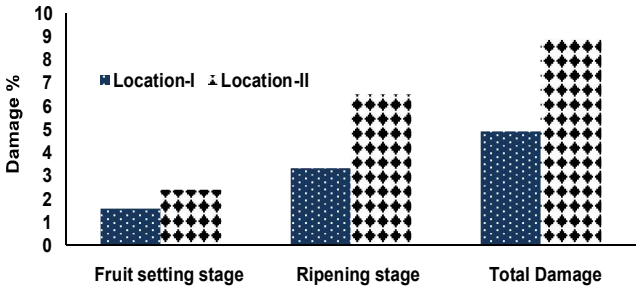

Fig. 5. Comparison of damage to guava crop by birds at location I and II

Table 2. Damage to guava fruit by birds at location I and II

Sampled trees	Total production of fruit (kg)		Undamaged production of fruit (kg)		Unripe fruit damage (kg)		Ripening fruit damage (kg)		Total fruit damage (kg)	
	L I	L II	L I	L II	L I	L II	L I	L II	L I	L II
Periphery of the orchard										
Total damage	333	263	316.5	240	5.60	6.97	12	16.03	17.60	23
% Damage			95.04%	91.25%	1.68%	2.65%	3.60%	6.09%	5.28%	8.74%
Middle of the orchard										
Total damage	344	240	328.25	218.2	5.26	5.09	10.49	16.71	15.75	21.8
% Damage			95.42%	90.92%	1.53%	2.12%	3.05%	6.96%	4.58%	9.08%
Overall total damage (kg)	677	503	644.75	458.2	10.86	12.06	22.49	32.74	33.35	44.8
Overall total damage (%)			95.23%	91.09%	1.60%	2.40%	3.32%	6.51%	4.92%	8.91%

L I-Location-I, L II- Location-II

respectively (4.92 % loss) (Table 2). Sidhu and Kler (2018) also recorded 5.5 % damage by birds to guava fruit at the PAU fruit research farm, due to the adoption of rigorous management measures. The damage to the guava was more in the ripening stage (3.32 %) as compared to the unripe stage (1.06 %). Hussain and Vashishat (2021) also observed same trend. At the periphery and middle of the orchard the damage was recorded 5.28 and 4.58 %, respectively. Khan et al (2015) and Senar et al (2016) also found that damage was fairly high on the edges of the crop, primarily due to the presence of trees, bushes and fencing along the edge suggesting the safety factors for the birds to exit in the unsuitable ecological conditions.

At location II, total fruit yield was 503 kg. Total weight of damaged fruit and healthy fruit was 44.80 and 458 kg respectively which was equal to 8.91 % loss. The findings are in line with those of Khan et al (2013) and Dulera and Nayi (2022) with damage of 8.01% and 11.66% respectively in unprotected guava fields due to Rose-ringed parakeet. The damage at ripen stage was 6.51% and at unripe stage was 2.40 %. At the periphery and middle of the orchard the damage was 8.74 and 9.08% respectively. Variation in damage from edge to interior is affected by factors such as crop size and the environmental surroundings of the field (Kale et al 2014). The maximum bird damage was recorded at location II, because manual scaring practices were not used on regular basis at location II (Fig. 5). Total mean damaged yield (kg) of guava fruit was 3.30±1.17 and 4.48±0.87 at location I and location II respectively. The statistical comparison showed the significant difference in the mean damage fruit yield of guava fruit at location I and II and implementation of bird scaring methods helped in reducing the damage at the location I.

CONCLUSION

Bird depredation on guava fruit remained fairly high in areas where manual scaring techniques were not used on ongoing basis. Situation was markedly improved with the implementation of intense management practices. Incorporation of manual scaring techniques significantly minimised bird damage while simultaneously maximised crop yield.

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Bird Diversity of Jagdishpur Jheel: An Unprotected Wetland in Ayodhya District, Uttar Pradesh

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***Abstract*:** Jagdishpur Jheel located in Ayodhya district, Uttar Pradesh, is an unprotected, perennial wetland which not only supports the economic activities of the local people but also acts as wintering and stopover site for migratory and resident birds. Point count surveys were conducted from October 2020 to September 2021 to record the diversity and status of birds in Jagdishpur jheel. A total of 78 bird species belonging to 61 genera, distributed among 33 families and 13 orders were recorded from Jagdishpur Jheel, of which 53 species (68%) were resident and 25 species (32%) were winter visitors. Ardeidae was the most dominant family with 8 species and the highest RDi value (10.26). The carnivore guild was the most dominant with 36 species (46%), followed by omnivore 31 species (40%), insectivore 10 species (13%) and frugivore with one species (1%). Of the species recorded, three species are classified as Vulnerable and four species as Near Threatened in the IUCN Red List of Threatened Species and supported 26 species (33%) of birds having a declining population trend globally. This study will provide a baseline for future research and monitoring of birds in this wetland.

***Keywords*:** Avifauna, Conservation, Feeding guild, Relative diversity, Threatened

Wetlands ecosystems are the most productive systems (Mitsch et al. 2009) and constitute 4% of earth's ice-free land area (Panigrahy et al 2012). They regulate groundwater recharge, pollutants, recreational activity and sustain life of numerous species of flora and fauna (Crisman 2001). The fauna of the wetlands is affected by biotic factors like availability of food, hunting and poaching activities, wetland size (Paracuellos 2006) and abiotic factors (Lagos et al 2008). In India, wetlands cover an area of 58.2 million hectares (Prasad et al 2002). Nearly 310 wetland dependent bird species are reported from India (Kumar et al 2005). Birds which are totally dependent on the wetlands for the development of their behavioral and physiological characters are known as waterbirds (Vargiya and Chakraborty 2019). The other bird groups which are ecologically dependent on wetlands are known as wetland dependent and associated birds (Kumar et al 2005). In Uttar Pradesh, 5.16% of the total geographic area is covered by wetlands and Ayodhya district in Uttar Pradesh has just 1.86% of the total land cover is under wetlands (NWA 2010). But none of the wetlands in Ayodhya district enjoy protected status. So, these wetlands in Ayodhya district are under tremendous anthropogenic pressure such as, encroachment, conversion into agricultural lands, dumping grounds, fishing grounds, eutrophication, nutrient run-off from surrounding lands etc. which affect the structure of bird communities present in these wetlands (Reginald et al 2007). Long-term monitoring of waterbirds provides information on the health and status of wetlands. Studies were conducted on bird diversity in protected wetlands such as Samaspur Bird Sanctuary, Rae Bareli (Kumar and Kanaujia 2015), Sandi Bird Sanctuary, Hardoi, (Kumar and Srivastava 2013), Nawabganj Bird Sanctuary, Unaao (Kumar et al 2015) and unprotected wetlands of Lucknow district (Kanaujia et al 2013). Bird diversity has been studied in the riverine (Yashmita-Ulman 2022a) and agricultural areas (Yashmita-Ulman 2022b) of Ayodhya district. But there have been no studies done in wetlands of Ayodhya district. The present study is based on the documentation of avifaunal species both waterbirds and wetland associated birds in one of the perennial but unprotected wetlands named Jagdishpur Jheel in Ayodhya district.

MATERIAL AND METHODS

Study site: The Jagdishpur jheel is one of the suitable habitats for waterbirds as it is a perennial wetland. It is situated 10 km from Faizabad city and lies between $26^0$43'55.20" N and $82^0$1'4.80" E. This wetland is situated in the Jagdishpur village of Sohawal tehsil of Ayodhya district and covers an area of about 12.6 ha. The wetland is surrounded by agricultural field on one side and by human habitation on the other side. The wetland varies in depth, i.e. contains shallow water at the exterior but gets deeper towards the interior of the wetland. The surrounding marshy

and agricultural area is suitable for waders and stork species. The grassland and the scattered trees of *Eucalyptus tereticornis, Phyllanthus emblica, Mangifera indica, Ficus religiosa, Ficus bengalensis, Terminalia arjuna* etc. also support diverse bird species. The wetland habors floating hydrophytes (*Azolla pinnata, Eichhornia cracipes, Jussiaea repens, Ipomoea aquatica*) and submerged hydrophytes (*Najas graminea, Potamogeton nodosus*). This wetland has a high human interference in the form of conversion of wetland into agricultural and fishing grounds, pumping of water for agricultural purpose and extraction of Water chestnut.

Method: Observations were recorded using point count method from October 2020 to September 2021. Two-point counts (Bibby et al 2000) were fixed 250 m apart from each other on the periphery of the Jagdishpur wetland such that the whole wetland could be covered visually. The observations were made whenever the visibility was good during winters (usually between 1100 to 1200 hrs) and early in the morning (from 0600 to 0700 hrs) during rest of the seasons. During the entire study period each point count was surveyed 24 times. At each point count, initial 5 mins was given for the birds to settle down and then bird species were recorded for the next 20 mins. Birds were observed with the help of binoculars (Nikon 7x35). Grimmett et al. (2011) was used for identification of birds and knowing its residential status. Praveen et al (2020) was referred for assigning the bird species its taxonomic positions and names and Ali and Ripley (1987) for classifying birds into feeding guilds. The conservation and global population status was assigned (IWPA 1972; CITES 2012; IUCN 2021). Torre-Cuadros et al (2007) was followed to calculate the relative diversity of bird families. The formula is given below:

$$RDi = \frac{\text{Number of bird species in a family}}{\text{Total number of species}} \times 100$$

RESULTS AND DISCUSSION

A total of 78 bird species belonging to 61 genera, distributed among 33 families and 13 orders were recorded from Jagdishpur Jheel during the study period (Table 1). This is higher than the bird species recorded at Chhaya Rann wetland, Gujarat (70 species) (Vargiya and Chakraborty 2019) and Chhilchhila Wildlife Sanctuary, Haryana (57 species) (Kumar and Gupta 2013), but lower than the bird species recorded at Suraha Tal lake, Uttar Pradesh (91 species) (Srivastava and Srivastava 2012) and Khaparwas Bird Sanctuary, Haryana (164 species) (Gupta et al 2012). Passeriformes had the highest diversity with 20 species and 11 families, followed by Charadriiformes with 18 species and 7 families. This result is similar to the findings of Kumar & Sharma (2018). Ardeidae was the most dominant family with 8 species and the highest RDi value (10.26) (Table 2). This finding conforms to that of Vyas et al. (2010) in Bhoj wetland, Madhya Pradesh, but is in contrast to the results of Karikar et al (2019) in Solapur, Maharashtra and Kumar and Gupta (2009) in Kurukshetra, Haryana, who reported Anatidae to be the most dominant family. This was followed by Scolopacidae with 7 species (Table 2). According to the residential status of the birds recorded, 53 species (68%) were resident and 25 species (32%) were winter visitors. Similar results were reported by Ahmed et al (2019) in Haripura-Baur reservoir, Uttarakhand and Karikar et al (2019) in wetlands of Solapur, Maharashtra. The occurrence of higher number of winter migrants must be due to the fact that this study area is a part of the Central Asian Flyway and therefore may act as a wintering and stop over site for the winter migrants that breed in the Palearctic zone (Kumar et al 2016). The winter birds started arriving from October and reached peak in December and January and slowly started moving out from February. The other resident birds stayed in the wetland throughout but their populations fluctuated.

Out of the four major feeding guilds identified, carnivore guild was the most dominant with 36 species (46%), followed by omnivore (40%), insectivore (13%) and frugivore (1%). The food quality and quantity are the major factors that attracts bird population towards a habitat (Jha 2013). The higher representation of carnivores and omnivores suggests the presence of diverse food resources in the jheel. Due to their specialized feeding structure, the frugivores were the least represented. Many of the wetland associated birds such as ducks, jacanas, kingfishers, storks, herons, egrets etc. fed on aquatic creatures namely, worms, amphibians, crustaceans, fish and insects at various depths of wetlands, adjacent marshy areas and agricultural fields. Apart from food, the wetland and its surrounding habitats also provide shelter, breeding and nesting sites to the wetland associated birds. The birds such as lapwings, thick-knees, Sarus cranes have been observed nesting in the habitats adjacent to this jheel.

The unprotected but perennial Jagdishpur Jheel supported three vulnerable species viz., *Antigone antigone, Aquila rapax* and *Sterna aurantia* and four near threatened species viz., *Anhinga melanogaster, Esacus recurvirostris, Mycteria leucocephala,* and *Vanellus duvaucelii* as per the IUCN Red List (IUCN 2021) (Table 1). Moreover, eight species were included in the Appendix-II of CITES (CITES 2012) (Table 1). Six species came under Schedule I of the Indian Wildlife (Protection) Act (1972) (Table 1). In addition to this, the wetland supported 26

Table 1. Checklist and status of bird species recorded in Jagdishpur jheel

Order/Family/Common name	Scientific name	Residential status	Feeding guild	Conservation status			
				IUCN list (2021)	CITES (2012)	IWPA (1972)	Global status
Accipitriformes Accipitridae (5)							
Black Kite	*Milvus migrans* (Boddaert 1783)	R	C	LC	II	I	?
Black-winged Kite	*Elanus caeruleus* (Desfontaines 1789)	R	C	LC	II	I	→
Indian Spotted Eagle	*Clanga hastata* (Lesson 1831)	R	C	LC	II	I	↓
Shikra	*Accipiter badius* (Gmelin 1788)	R	C	LC	II	I	→
Tawny Eagle	*Aquila rapax* (Temminck 1828)	R	C	VU	II	I	↓
Pandionidae (1)							
Osprey	*Pandion haliaetus* (Linnaeus 1758)	WV	C	LC	II	I	↑
Anseriformes Anatidae (6)							
Bar-headed Goose	*Anser indicus* (Latham 1790)	WV	O	LC	-	IV	↓
Cotton Pygmy-goose	*Nettapus coromandelianus* (Gmelin 1789)	R	O	LC	-	IV	→
Garganey	*Spatula querquedula* (Linnaeus 1758)	WV	O	LC	-	IV	↓
Indian Spot-billed Duck	*Anas poecilorhyncha* (Forster 1781)	R	O	LC	-	IV	↓
Lesser Whistling Duck	*Dendrocygna javanica* (Horsfield 1821)	R	O	LC	-	IV	↓
Northern Pintail	*Anas acuta* (Linnaeus 1758)	WV	O	LC	-	IV	↓
Charadriiformes Burhinidae (2)							
Great Thick-knee	*Esacus recurvirostris* (Cuvier 1829)	R	C	NT	-	IV	↓
Eurasian Thick-knee	*Burhinus ioedicnemus* (Linnaeus 1758)	R	O	LC	-	IV	↓
Charadriidae (5)							
Kentish Plover	*Charadrius alexandrinus* (Linnaeus 1758)	WV	C	LC	-	IV	↓
Little Ringed Plover	*Charadrius dubius* (Scopoli 1786)	R	O	LC	-	IV	→
Red-wattled Lapwing	*Vanellus indicus* (Boddaert 1783)	R	O	LC	-	IV	?
River Lapwing	*Vanellus duvaucelii* (Lesson 1826)	R	C	NT	-	IV	↓
Yellow-wattled Lapwing	*Vanellus malabaricus* (Boddaert 1783)	R	C	LC	-	IV	→
Jacanidae (1)							
Bronze-winged Jacana	*Metopidius indicus* (Latham 1790)	R	O	LC	-	IV	?
Laridae (1)							
River Tern	*Sterna aurantia* (Gray 1831)	R	C	VU	-	IV	↓
Recurvirostridae (1)							
Black-winged Stilt	*Himantopus himantopus* (Linnaeus 1758)	WV	C	LC	-	IV	↑
Rostratulidae (1)							
Greater Painted-snipe	*Rostratula benghalensis* (Linnaeus 1758)	R	O	LC	-	IV	↓
Scolopacidae (7)							
Common Greenshank	*Tringa nebularia* (Gunnerus 1767)	WV	C	LC	-	IV	→
Common Redshank	*Tringa totanus* (Linnaeus 1758)	WV	C	LC	-	IV	?
Common Sandpiper	*Actitis hypoleucos* (Linnaeus 1758)	WV	C	LC	-	IV	↓
Green Sandpiper	*Tringa ochropus* (Linnaeus 1758)	WV	O	LC	-	IV	↑
Little Stint	*Calidris minuta* (Leisler 1812)	WV	O	LC	-	IV	↑
Temminck's Stint	*Calidris temminckii* (Leisler 1812)	WV	O	LC	-	IV	?
Wood Sandpiper	*Tringa glareola* (Linnaeus 1758)	WV	O	LC	-	IV	→
Pelecaniformes Ciconiidae (2)							
Asian Openbill	*Anastomus oscitans* (Boddaert 1783)	R	C	LC	-	IV	?

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Order/Family/Common name	Scientific name	Residential status	Feeding guild	Conservation status			
				IUCN list (2021)	CITES (2012)	IWPA (1972)	Global status
Painted Stork	*Mycteria leucocephala* (Pennant 1769)	WV	C	NT	-	IV	↓
Columbiformes Columbidae (1)							
Yellow-footed Green-pigeon	*Treron phoenicopterus* (Latham 1790)	R	F	LC	-	IV	↑
Coraciiformes Alcedinidae (3)							
Common Kingfisher	*Alcedo atthis* (Linnaeus 1758)	R	C	LC	-	IV	?
Pied Kingfisher	*Ceryle rudis* (Linnaeus 1758)	R	C	LC	-	IV	?
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus 1758)	R	C	LC	-	IV	↑
Falconiformes Falconidae (1)							
Common Kestrel	*Falco tinnunculus* (Linnaeus 1758)	WV	C	LC	II	IV	↓
Gruiformes Gruidae (1)							
Sarus Crane	*Antigone* (Linnaeus 1758)	R	O	VU	-	IV	↓
Rallidae (5)							
Common Coot	*Fulica atra* (Linnaeus 1758)	R	O	LC	-	IV	↑
Common Moorhen	*Gallinula chloropus* (Linnaeus 1758)	R	O	LC	-	IV	→
Purple Swamphen	*Porphyrio* (Linnaeus 1758)	R	O	LC	-	IV	?
Watercock	*Gallicrex cinerea* (Gmelin 1789)	R	C	LC	-	IV	↓
White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant 1769)	R	O	LC	-	IV	?
Passeriformes Acrocephalidae (1)							
Blyth's Reed Warbler	*Acrocephalus dumetorum* (Blyth 1849)	WV	O	LC	-	IV	↑
Alaudidae (1)							
Sand Lark	*Alaudala raytal* (Blyth 1845)	R	O	LC	-	IV	→
Cisticolidae (2)							
Ashy Prinia	*Prinia socialis* (Sykes 1832)	R	I	LC	-	IV	→
Plain Prinia	*Prinia inornata* (Sykes 1832)	R	I	LC	-	IV	→
Dicruridae (1)							
Black Drongo	*Dicrurus macrocercus* (Vieillot 1817)	R	C	LC	-	IV	?
Estrildidae (1)							
Scaly-breasted Munia	*Lonchura punctulata* (Linaeus 1758)	R	O	LC	-	IV	→
Hirundinidae (3)							
Barn Swallow	*Hirundo rustica* (Linnaeus 1758)	WV	I	LC	-	IV	↓
Streak-throated Swallow	*Petrochelidon fluvicola* (Blyth 1855)	R	I	LC	-	IV	↑
Wire-tailed Swallow	*Hirundo smithii* (Leach 1818)	R	I	LC	-	IV	↑
Leiothrichidae (1)							
Common Babbler	*Argya caudata* (Dumont 1823)	R	O	LC	-	IV	→
Motacillidae (4)							
Citrine Wagtail	*Motacilla citreola* (Pallas 1776)	WV	I	LC	-	IV	↑
Grey Wagtail	*Motacilla cinerea* (Tunstall 1771)	WV	I	LC	-	IV	→
Western Yellow Wagtail	*Motacilla flava* (Linnaeus 1758)	WV	I	LC	-	IV	↓
White-browed Wagtail	*Motacilla maderaspatensis* (Gmelin 1789)	R	I	LC	-	IV	→
Muscicapidae (1)							
Black Redstart	*Phoenicurus ochruros* (Gmelin 1774)	WV	I	LC	-	IV	↑

Cont...

Table 1. Checklist and status of bird species recorded in Jagdishpur jheel

Order/Family/Common name	Scientific name	Residential status	Feeding guild	Conservation status			
				IUCN list (2021)	CITES (2012)	IWPA (1972)	Global status
Passeridae (1)							
House Sparrow	*Passer domesticus* (Linnaeus 1758)	R	O	LC	-	IV	↓
Sturnidae (4)							
Asian Pied Starling	*Gracupica contra* (Linnaeus 1758)	R	O	LC	-	IV	↑
Bank Myna	*Acridotheres ginginianus* (Latham 1790)	R	O	LC	-	IV	↑
Brahminy Starling	*Sturnia pagodarum* (Gmelin 1789)	R	O	LC	-	IV	?
Common Myna	*Acridotheres tristis* (Linnaeus 1766)	R	O	LC	-	IV	↑
Pelecaniformes Ardeidae (8)							
Black-crowned Night Heron	*Nycticorax nycticorax* (Linnaeus 1758)	R	O	LC	-	IV	↓
Cattle Egret	*Bubulcus ibis* (Linnaeus 1758)	R	C	LC	-	IV	↑
Great Egret	*Ardea alba* (Linnaeus 1758)	R	C	LC	-	IV	?
Grey Heron	*Ardea cinerea* (Linnaeus 1758)	WV	C	LC	-	IV	?
Indian Pond Heron	*Ardeola grayii* (Sykes 1832)	R	C	LC	-	IV	?
Intermediate Egret	*Ardea intermedia* (Wagler 1829)	R	C	LC	-	IV	?
Little Egret	*Egretta garzetta* (Linnaeus 1766)	R	C	LC	-	IV	↑
Purple Heron	*Ardea purpurea* (Linnaeus 1766)	R	C	LC	-	IV	↓
Threskiornithidae (1)							
Red-naped Ibis	*Pseudibis papillosa* (Temminck 1824)	WV	C	LC	-	IV	↓
Phoenicopteriformes Podicipedidae (1)							
Little Grebe	*Tachybaptus ruficollis* (Pallas 1764)	R	C	LC	-	IV	↓
Strigiformes Strigidae (2)							
Jungle Owlet	*Glaucidium radiatum* (Tickell 1833)	R	C	LC	-	IV	→
Spotted Owlet	*Athene brama* (Temminck 1821)	R	C	LC	II	IV	→
Pelecaniformes Anhingidae (1)							
Oriental Darter	*Anhinga melanogaster* (Pennant 1769)	WV	O	NT	-	IV	↓
Phalacrocoracidae (2)							
Indian Cormorant	*Phalacrocorax fuscicollis* (Stephens 1826)	WV	C	LC	-	IV	?
Little Cormorant	*Microcarbo niger* (Vieillot 1817)	R	C	LC	-	IV	?

IUCN: International Union for Conservation of Nature and Natural Resources; CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora; IPWA: Indian Wildlife Protection Act; R: Resident, WV: Winter Visitor; C: Carnivorous; O: Omnivorous; I: Insectivorous; F: Frugivorous; LC: Least Concern; VU: Vulnerable; NT: Near Threatened; CITES II: Schedule-II species of CITES are the ones that are not necessarily threatened now with extinction but may become so unless trade is closely controlled; IWPA I: Schedule - I species of IWPA (high priority species); IV: Schedule - IV species of IWPA (relatively low priority species); ?: Unknown; —: Stable; ↑: Increasing; ↓: Decreasing

Table 2. Relative diversity (Rdi) of various bird families in Jagdishpur jheel

Avian family	Number of species recorded	Rdi value
Ardeidae	8	10.26
Scolopacidae	7	8.97
Anatidae	6	7.69
Accipitridae	5	6.41
Charadriidae	5	6.41
Rallidae	5	6.41
Motacillidae	4	5.13
Sturnidae	4	5.13
Alcedinidae	3	3.85
Hirundinidae	3	3.85
Burhinidae	2	2.56
Ciconiidae	2	2.56
Cisticolidae	2	2.56
Strigidae	2	2.56
Phalacrocoracidae	2	2.56
Pandionidae	1	1.28
Jacanidae	1	1.28
Laridae	1	1.28
Recurvirostridae	1	1.28
Rostratulidae	1	1.28
Columbidae	1	1.28
Falconidae	1	1.28
Gruidae	1	1.28
Acrocephalidae	1	1.28
Alaudidae	1	1.28
Dicruridae	1	1.28
Estrildidae	1	1.28
Leiothrichidae	1	1.28
Muscicapidae	1	1.28
Passeridae	1	1.28
Threskiornithidae	1	1.28
Podicipedidae	1	1.28
Anhingidae	1	1.28

species (33%) of birds having a declining population trend globally. This result highlights the conservation importance of a wetland which is totally exposed to human interference but yet has the potential to conserve globally threatened, migratory and population declining bird species. The wetland due to its variation in water depth and surrounding habitat such as grasses, agriculture and scattered trees attract the resident as well as migratory species. It provides the birds with permanent and temporary refuge sites, foraging, nesting and breeding sites.

CONCLUSION

It is evident from the present study that though the Jagdishpur jheel does not enjoy any protection status, it serves as a good site for habouring and nurturing avifauna especially of threatened and migratory category. This study has helped develop a baseline data of the wetland based on which further long-term monitoring studies can be taken up emphasising on the importance of the wetland in terms of breeding and nesting sites. Conservation measures can also be implemented with the help of the local people of the study area.

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Impact of Urban Landscape on Relative Abundance of Invasive Bird Species

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***Abstract*:** Invasive species owing to their habitat flexibility are able to exploit the ample feeding and nesting resources offered by urban landscapes. The current study was conducted in Jalandhar city of northwest India, where all the studied transects reported a relative abundance of more than 75% for invasive bird species. Tree species diversity was the most important habitat feature that positively affected bird species richness, species diversity and species evenness, while also reducing the relative abundance of invasive bird species. Hence a better planning of urban vegetative cover can help us maintain a more diverse urban avifauna.

***Keywords*:** Urban birds, Invasive species, Urban biodiversity, Urban avifauna

Invasive species are becoming a part of ecosystems all over the world and irreversibly changing their biodiversity (Capinha et al 2015, Dawson et al 2017). Several studies have recognized the negative impact of invasive species, causing decline in native species, economic damages, and transmission of diseases in plants, animals, and humans (Crowl et al 2008, Dove at al 2011, Ahmad et al 2012). The Global Invasive Species Database (2015) enlists 16 invasive bird species present in India with four recognized as Alien Invasive and 12 as Native Invasive species. The distribution of invasive species is determined by various factors differing in their importance and the interaction between these factors throughout the process of invasion (Blackburn et al 2011). The dominance of an invasive species in a habitat can be through two pathways: direct competition for resources, or being resistant to environmental stressors that limit other species. The later known as 'passenger model' has more support in recent studies where native species have declined due to environmental pressures forming an empty niche which is exploited by invasive species (Sol et al 2012). Growing urban centres with their constantly changing landscape offer new niches to be exploited by opportunistic species, and invasive species are often the ones to take advantage of these newly available resources (González-Oreja et al 2018). Blackburn et al (2009) stated that most successful invasive birds prefer habitats disturbed by humans which are avoided by indigenous species. Invasive bird species threaten the native bird diversity of a place, so much so that some countries adopt various methods to capture and control their population (Abd Rabou 2022). Urbanization is considered a primary threat to birds all over the world (SoIB 2020). In the past 20 years in India, urban cover in the top 100 cities alone has increased by almost 2.5-fold, by an extent greater than 5000 km^2 area (Nagendra et al 2014). This study aimed to understand the factors affecting the spatial distribution of invasive bird species in urban centres.

MATERIAL AND METHODS

Study area: The study was carried out in Jalandhar city (31.3260° N, 75.5762° E) situated in the northwestern state of Punjab, India. It has a humid subtropical climate with temperature ranging from 5ºC in winters to as high as 45 ºC in summers. Two transects 1 km each were selected from residential (R I and R II), commercial (C I and C II) and industrial areas (In I and In II) of the city to study bird composition.

R I – Unplanned residential area with narrow lanes and double-story houses with old infrastructure. The vegetation included one large *Ficus benghalensis* tree apart from a few short trees and bushes.

R II – Well planned residential area with wider roads and modern houses. In addition to two public parks, the vegetation comprised of several roadside trees, and gardens in homes with short trees, bushes, and seasonal flowering plants.

C I – It was an unplanned commercial area with heavy footfall for most part of the day and almost no vegetation except for one *Ficus religiosa* tree. The marketplace had mostly single or double-story shops with a residence on the upper floor.

C II – A well-planned marketplace with wide roads, a public park, and several shops and shopping complexes. Roads having heavy vehicular traffic in the evening.

In I – This was an industrial area having factories with high metal roofs. Vegetation mostly consisted of short trees along the outer walls of factories, most common being *Saraca asoca* that were regularly pruned and kept short.

In II – This industrial area was on the outskirts of the city having agricultural fields close by. The infrastructure was similar to that of transect In I. The vegetation comprised of several large trees and empty plots with wild grasses and shrubs.

Bird and vegetation surveys: Line transects method was followed for conducting bird surveys in the selected transects (Verner 1985). Surveys were conducted weekly, for a period of one year from July 2018 to June 2019. Birds were identified based on The Book of Indian Birds (Ali 2002) and Birds of the Indian Subcontinent (Grimmett et al 2016). The common and scientific names of birds were given according to Praveen et al (Praveen et al 2016). Information on the enlisted invasive bird species was taken from the Global Invasive Species Database (GISD 2015).

Tree species were recorded and identified based on trees of Delhi. A field guide (Krishen 2006) and The Book of Indian Trees (Sahni 1998). Land cover data including built cover, road cover and green cover was obtained from Punjab Remote Sensing Centre, Ludhiana (Punjab).

Data analysis: Habitat features including percentage road cover, percentage green cover, tree species richness and tree count were the independent variables for regression analysis. Four ecological indexes were taken as dependent variables: Bird species richness, species diversity, species evenness and bird count per observation. Regression analysis was carried out using SPSS Version 23, to analyse the association between habitat features and ecological indices.

RESULTS AND DISCUSSION

During the present study, a total of 50 bird species belonging to 29 families and 13 orders were recorded (SS 1). Bird species richness varied from 15 in transect C I to 34 in transect In II. Among the bird species recorded, seven species fall under the category of invasive species, namely Rock Pigeon (*Columba livia*), Common Myna (*Acridotheres tristis*), Eurasian Collared-Dove (*Streptopelia decaocto*), House Crow (*Corvus splendens*), House Sparrow (*Passer domesticus*), Red-vented Bulbul (*Pycnonotus cafer*) and Rose-ringed Parakeet (*Psittacula krameri*). All transects had six to seven invasive species while the native species richness varied from 9 to 28. Transect R I and C I had the lowest native species richness while In II had the maximum number of native bird species (Table 2). The total percent abundance of invasive bird species was highest in transect C I (98.33%), followed by R I, R II, and C II. The abundance of invasive species was comparatively lower in transects In I (77.72%) and In II (75.71%) than other transects (Table 3).

Road cover significantly decreased bird species richness, species diversity and species evenness by 0.46 (β = -0.64), 0.09 (β = -0.91) and 0.03 (β = -0.88) respectively (Table 4).

Table 1. Habitat features of six selected transects

Transect components	R I	R II	C I	C II	In I	In II
Built cover (%)	89.66	69.57	92.4	66.08	88.12	80.27
Road cover (%)	7.79	18.47	6.47	2.24	1.72	1.99
Green cover (%)	2.54	11.95	1.13	31.69	10.17	17.73
Public parks	-	2	-	1	-	1
Average road width	3 m	4 m	2.5 m	8 m	5 m	4.5 m
Tree species richness	13	42	1	20	24	22
Tree count	25	361	1	92	301	143

- Absent

Table 2. Species richness and relative abundance of birds from different nativity status in the selected transects

Transects	Total species richness	Native species		Invasive species	
		Richness	Abundance	Richness	Abundance
R I	17	10	0.15	7	0.85
R II	30	23	0.15	7	0.85
C I	15	9	0.02	6	0.99
C II	24	18	0.16	6	0.84
In I	30	23	0.22	7	0.78
In II	34	28	0.24	6	0.76

Green cover significantly increased the bird count per observation by 3.30 (β = 1.55) while it decreased the bird diversity by 0.02 (β = -0.39) and evenness by 0.01 (β = -0.44). Tree species richness significantly increased the bird species richness, species diversity and species evenness by 0.39 (β = 1.15), 0.11 (β = 2.33) and 0.04 (β =2.52) respectively. Tree count significantly increased the bird count per observation by 0.25 (β = 1.56) but was related to decreased bird species diversity and evenness. The tree species richness increased bird species richness, species diversity as well as evenness while tree count increased the bird count per observation. The tree species richness is more important than green cover and tree number for the sustenance of a diverse urban avifauna. Road cover decreased bird species richness, species diversity and species evenness but bird count per observation. Since road cover is an indicator of urbanization, it may be derived that although urban habitats may show larger bird count, the species richness, diversity and evenness is low. This is an indication for species homogeneity recorded in various studies based in urban habitats. Road cover and green cover significantly increased the abundance of invasive species by 1.77 (β = 1.20) and 0.51 (β = 0.60), respectively (Table 4). Tree species richness significantly decreases the abundance of invasive species by 1.47 (β = -2.09). Tree count on the other hand increased the invasive species abundance by 0.06 (β = 0.86).

Road cover had the most positive effect on the abundance of invasive species. Of all the studied independent variables, only tree species diversity had a significant negative impact on the abundance of invasive species. Over the years several studies have shown the negative impact of urbanization on local biodiversity, both floral and faunal (Evans et al 2009). The success of invasive bird species has been attributed to their ability to exploit ecological opportunities that most native bird species are not able to (Sol et al 2012 and González-Oreja at al 2018). Several studies have shown an increase in taxonomic homogenization in urban centres (Crooks et al 2004 and Menon and Mohanraj 2016). Similar results were observed in

Table 3. Relative abundance of Invasive bird species at selected transects (%)

Invasive bird species	R I	R II	C I	C II	In I	In II	Overall
Rock pigeon	50.71	23.88	87.25	29.35	42.04	24.99	43.04
Common Myna	8.65	8.75	3.35	16.81	6.09	17.52	10.2
Eurasian collared-dove	9.83	8.86	3.12	5.36	9.25	13.65	8.34
House crow	5.34	16.05	2.91	21.78	6.71	7.5	10.05
House sparrow	6.07	16.69	-	-	0.37	-	3.85
Red-vented bulbul	4.5	8.14	1.01	3.99	11.2	6.1	5.82
Rose-ringed parakeet	0.31	2.6	0.69	6.56	2.06	5.95	3.03
Total abundance	85.41	84.97	98.33	83.85	77.72	75.71	84.33

- Absent

Table 4. Effect of habitat features on bird species richness, species diversity, species evenness, bird count per observation and abundance of invasive species

Parameter	Species richness		Species diversity		Species evenness		Bird count per observation		Invasive species abundance	
	B (SE)	Beta	B (SE)	Beta	B (SE)	Beta	B (SE)	Beta	B (SE)	Beta
Constant	9.17 (0.71)		1.09 (0.03)		0.47 (0.01)		39.83 (2.56)		87.84 (1.30)	
Road cover (%)	-0.46 (0.10)	-0.64*	-0.09 (0.00)	-0.91*	-0.03 (0.00)	-0.88*	3.80 (0.37)	1.02*	1.77 (0.19)	1.20*
Green cover (%)	-0.06 (0.06)	-0.14	-0.02 (0.00)	-0.39*	-0.01 (0.00)	-0.44*	3.30 (0.21)	1.55*	0.51 (0.11)	0.60*
Tree species diversity	0.39 (0.11)	1.15*	0.11 (0.01)	2.33*	0.04 (0.00)	2.52*	-3.88 (0.38)	-2.19*	-1.47 (0.19)	-2.09*
Tree count	0.00 (0.01)	-0.15	0.00 (0.00)	-1.03*	0.00 (0.00)	-1.25*	0.25 (0.03)	1.56*	0.06 (0.01)	0.86*
R^2		0.60		0.95		0.92		0.82		0.70
Adjusted R^2		0.58		0.95		0.92		0.81		0.68

*p < 0.001

the present study with few invasive bird species forming more than 75% of species abundance in all transects. Previous studies have also recorded the spatial association between alien bird species and high human density (Hugo and Rensburg 2009). McLean et al (2017) cautioned that urban centres may become launching sites for invasive species into peri-urban and natural habitats making it all the more important to study the habitat factors that affect the success of invasive species in the cities. The most densely urbanized and unplanned transects, R I and C I showed the lowest bird species richness, which may be attributed to their lower tree species richness compared to planned residential areas, and industrial areas on the outskirts of city. Sub-urban areas can have a higher bird species richness due to villages and village ponds attracting a variety of bird species (Sekhon et al 2023). Trees species richness was observed to have a strong positive effect on the bird species richness, species diversity as well as evenness. The negative impact of road cover on bird species richness, species diversity and evenness also explain the lower bird diversity observed in densely urbanized regions. Kaushik et al (2020) also observed that the size of urban green patches and tree richness were important factors affecting bird species richness and density.

Tree species diversity had a significantly positive impact on urban bird diversity and also related to low abundance of invasive bird species. In a similar study, bird species diversity was positively related to shrub species richness where birds preferred gardens with high tree and shrub species richness (Parker et al 2014). In the same study it was observed that native bird species preferred native tree species for feeding while alien bird species preferred alien tree species. Other studies have reported an increase in bird species richness with increase in size of urban green spaces and presence of native forests (Carbó-Ramírez and Zuria 2011 and Dale 2018). Retaining established native trees has also been reported to be effective in maintaining higher bird diversity in new urban centres (Barth et al 2015). Karjee et al (2022) conducted a study in a peri-urban area of east India and found that agricultural fields and degraded croplands helped maintain bird diversity. Increase in road cover, green cover and tree count had a positive impact on invasive species while tree species richness decreased the abundance of invasive bird species. Similar results were obtained by Tu et al (2020) where building area had a positive impact on number of birds. Studies report higher bird counts in cities where a few species dominate the urban landscape with high numbers (Ortega-Álvarez and MacGregor-Fors 2009 and Yuan and Lu 2016). Often similar to the present study these species are invasive bird species which exploit the various feeding and nesting opportunities provided by the cities.

CONCLUSION

The current urban landscape provides an unequal advantage to the invasive species and simply increasing urban green cover is not sufficient. There is a need for planned urban greening with the focus on increasing the vegetative diversity of the cities to maintain a diverse urban avifauna.

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Evaluation of Biochemical and Sensory Parameters of Pomegranate Beverage by the Incorporation of Quinoa Extract

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Abstract: The present study was conducted on optimization and hypocholesterolemic activity of pomegranate beverage with the incorporation of quinoa extract in order to assess the biochemical and sensory evaluation of pomegranate beverage with the incorporation of quinoa extract. Eight treatments were formulated at different concentrations of pomegranate juice (80, 85 and 90%) and quinoa extract (10, 15 and 20%) by altering the sugar level (15 and 18° brix) and compared with control (100% pomegranate juice). Among the eight different treatments, there was no significant difference was observed for sensory quality Significantly maximum total phenols (463.33 mg GAE/100 mL), DPPH radical scavenging activity (98.05%), potassium (718.83 mg/100 mL), phosphorous (201.58 mg/100 mL), calcium (194 mg/100 mL), magnesium (66.80 mg/100 mL), iron (3.26 mg/100 mL) and zinc (0.43 mg/100 mL) were identified in T_4 (80% Pomegranate juice + 20% quinoa extract + Sugar 15º Brix).

Keywords: Pomegranate, Quinoa extract, Phenols, Sensory evaluation, TSS, pH, DPPH, Tannin, Minerals

Pomegranate (*Punica granatum* L.) is a fruit-bearing shrub in the family 'Lythraceae'. The edible part of the fruit (arils-pulp bearing seeds) contains considerable amounts of acids, sugars, vitamins (A, C and E), polysaccharides, polyphenols and important minerals (Vardin and Fenercioglu 2003). Punicalagin has anti-inflammatory, anti-cancer and anti-atherosclerotic effects, according to studies. Pomegranate polyphenols are capable of limiting the body's reaction to reactive oxygen species (ROS) (Aloqbi et al 2016).

Quinoa (*Chenopodium quinoa Wild*.) is a crop used by pre-Columbian cultures in South America for centuries. It is one of the most nutritious grains used as human food. In recent years, research into nutritional strategies aiming to prevent excess energy intake has increased in response to rising levels of obesity and obesity-related diseases. Drug treatments or supplements of bioactive molecules are ineffective or exhibit adverse side effects, focus has shifted towards natural dietary components with potential impact upon appetite and satiety. Synergetic effect of pomegranate beverage with the incorporation of quinoa extract may be beneficial to improve the health. With this background, the present study was conducted on optimization and to assess the biochemical and sensory evaluation of pomegranate beverage with the incorporation of quinoa extract.

MATERIAL AND METHODS

The present investigation was undertaken at College of Horticulture, Bagalkot, Karnataka, India. The pomegranate fruits (cv. Bhagwa) were procured from Bellary district and were sorted, graded and washed thoroughly in running water and cut into halves with the help of sharp stainless steel knife. Fruits were placed in the hand operated pomegranate juice extractor and pressed to obtain juice. After extraction, juice was allowed to settle down and subsequently it was strained through clean muslin cloth to get a clear juice extract. Quinoa seeds were procured from Department of Vegetable Science, College of Horticulture, Bagalkot. Extract of quinoa was obtained by the procedure as presented in Figure 1. The extracted juice of pomegranate and quinoa were used as per treatments (Table 1) and sucrose was added to maintain TSS. Quinoa extract was added wherever needed in all the treatments at different percentages (except T_1 and T_5). The prepared beverage was filled in clean, sterilized bottles and sealed with caps and stored at 4° C. Experiment was conducted in three replications for sensory and biochemical analysis.

Sensory evaluation: The sensory evaluation of developed pomegranate beverage by incorporation of quinoa extract was evaluated by a panel of semi trained judges (n=10) on a nine point hedonic scale using sensory score sheet.

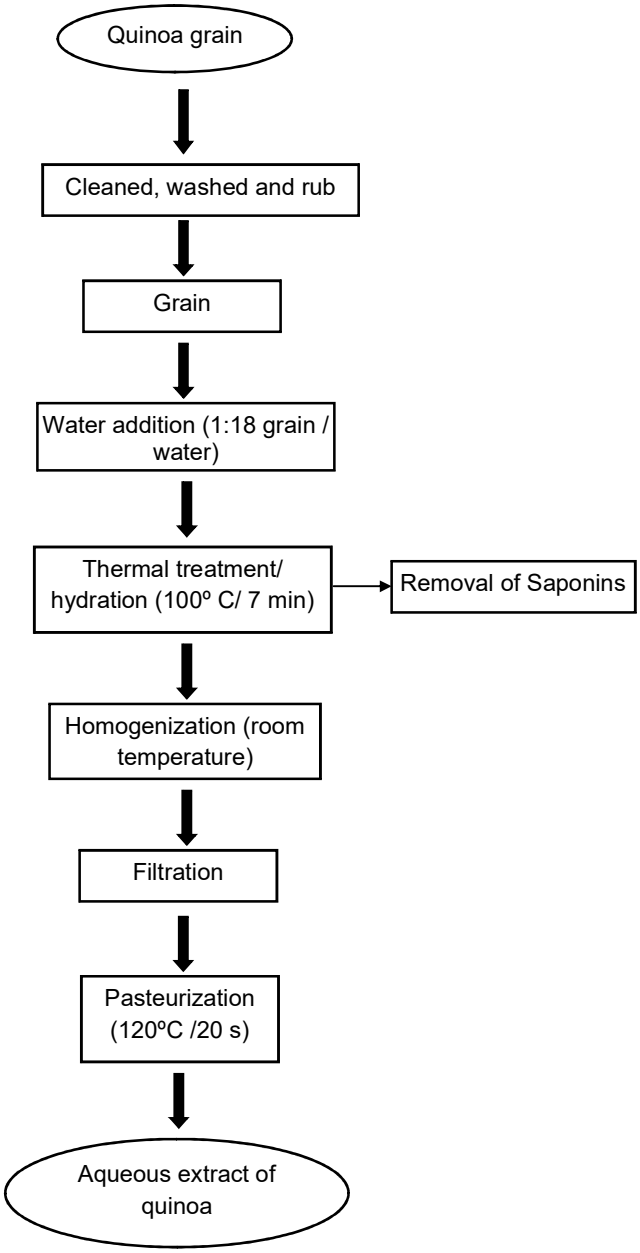

Fig. 1. Method of preparation of quinoa extract

Table 1. Treatments details of the experiment

T_1	100 % Pomegranate juice + Sugar (15° Brix) (Control-I)
T_2	90 % Pomegranate juice + 10% quinoa extract + Sugar (15° Brix)
T_3	85% Pomegranate juice + 15% quinoa extract+ Sugar (15° Brix)
T_4	80% Pomegranate juice + 20% quinoa extract + Sugar (15° Brix)
T_5	100 % Pomegranate juice + Sugar (18° Brix) (Control-II)
T_6	90 % Pomegranate juice + 10% quinoa extract + Sugar (18° Brix)
T_7	85% Pomegranate juice + 15% quinoa extract+ Sugar (18° Brix)
T_8	80% Pomegranate juice + 20% quinoa extract + Sugar (18° Brix)

Biochemical parameters: At room temperature, total soluble solids content of pomegranate beverage incorporated with quinoa extract was measured using a hand refractometer (Erma, Japan) in °Brix. The titratable acidity of pomegranate beverage incorporated with quinoa extract was estimated by the titration method. A known quantity of sample (5 mL) was taken and titrated against standard 0.1N NaOH using phenolphthalein indicator (Srivastava and Sanjeevkumar 1998). pH of the pomegranate beverage incorporated with quinoa extract was determined by using pH meter. To calibrate the instrument, standard buffer solutions of pH 4.0, 7.0 and 9.2 were used (Jackson 1969). The brix to acid ratio was estimated using the formula by taking the ratio of total soluble solids to titratable acidity.

***L*, a*,* and *b**colour values:** The colour of the pomegranate beverage incorporated with quinoa extract was assessed using a Hunter Lab colorimeter with a 45 mm (diameter) measurement tube. These three colour readings per sample were recorded using the *L*, a**, and *b** lightness (white-black), red-green and yellow-blue scales, respectively.

Phenols, DPPH free radical scavenging activity and tannin: For the determination of total phenols, methanol extracts (80 %) of pomegranate beverage incorporated with quinoa extract, folin-ciocalteu reagent method was followed using gallic acid as a standard (Madaan et al 2011). The ability of pomegranate beverage incorporated with quinoa extract to scavenge the stable 2, 2'-diphenyl-2-picrylhydrazyl (DPPH) free radical was assessed according to the method of Eghdami and Asli (2010). Tannin content of pomegranate beverage incorporated with quinoa extract was estimated by vanillin hydrochloride method using tannic acid as a standard (Sadasivam and Manickam 2015).

Minerals estimation: Potassium content in juice samples were estimated by using flame photometric method. Feed the di-acid or tri-acid digested sample to the flame photometer through a capillary tube and record reading (Jackson 1973).The phosphorous content present in the di-acid or tri-acid digested pomegranate beverage incorporated with quinoa extract reacts with vanadium and molybdenum in vanodomolybdate reagents to form 12 fold heteropoly phosphor-vanadomolybdate complex (Arora et al 2002). The filtrate after wet digestion by di-acid mixture was used for iron and zinc estimation by "Micro-wave plasma atomic emission spectrometer" instrument from Agilent Technologies. Calcium and magnesium was determined by complexo-metric titration method involving standard EDTA (Piper 1966).

The data was analyzed as applicable to completely randomized design (CRD). Statistical analyses of experiments were performed using Web Agri Stat Package (WASP) Version 2 (Jangam and Thali 2010).

RESULTS AND DISCUSSION

Sensory evaluation: Colour is the most important factor in determining consumer preference (Table 2). The maximum score was in control II T_5 (100 % pomegranate juice + sugar 18º Brix: 8.42) which was on par with control I T_1 (100 % pomegranate juice + sugar 15º Brix: 8.39). The control sample got the highest score because of its natural bright red colour and the quinoa extract incorporated sample scored less upon concentration however, they did not vary significantly. Incorporation of quinoa extract (10, 15%and 20%) to the pomegranate beverage did not vary consistency significantly. The addition of quinoa extracts does not change the taste and flavored pomegranate beverage significantly. Overall acceptability of pomegranate beverage incorporated with quinoa extract does not make any significant change. The overall acceptability of pomegranate beverage by incorporation of quinoa extract recorded highest score in T_1 which was at par with T_5 (100 % Pomegranate juice + Sugar 18º Brix: 8.07). Based on the above sensory information with all the quality parameters, there was no significant difference between the control and quinoa extract incorporated pomegranate beverage. It indicates that quinoa extract can be used for substitution of pomegranate beverage.

Biochemical parameters: There was a significant difference in TSS between the treatments (Table 3). The four treatments (T_1, T_2, T_3 and T_4) were maintained TSS of 15º Brix and (T_6, T_7 and T_8) 18º Brix. The maximum TSS (18.20^{0}Brix) content was in the treatment T_8 (80% Pomegranate juice + 15 % quinoa extract+ Sugar 15º Brix) and minimum (15.04 ºBrix) was in T_4 (80 % Pomegranate juice + 20% quinoa extract+ Sugar 15º Brix). The pH in T_8 was highest (3.66) and the lowest 3.54 was in control I. As the per cent incorporation of quinoa extract increased in the treatments, the pH also increased proportionately both in 15^o brix and 18^o brix. This may be due to more pH value of quinoa extract than pomegranate juice. Bianchi et al. (2015) also reported that

Table 2. Sensory evaluation of pomegranate beverage by incorporation of quinoa extract

Treatments	Colour and appearance	Consistency	Taste	Flavour	Overall acceptability
T_1	8.39	8.05	7.89	8.22	8.14
T_2	8.25	7.80	8.03	7.91	7.99
T_3	8.08	7.80	7.78	7.89	7.88
T_4	7.86	7.78	7.64	7.61	7.73
T_5	8.42	7.83	7.89	8.11	8.07
T_6	8.20	7.83	7.89	7.89	7.96
T_7	8.11	8.05	7.83	7.89	7.98
T_8	7.91	7.89	8.17	7.94	7.98
Mean	8.15	7.88	7.89	7.93	7.96
CD (p=0.01)	NS	NS	NS	NS	NS

See Table 1 for treatment detail

Table 3. Effect of incorporation of quinoa extract on total soluble solids, pH, titratable acidity, brix to acid ratio and colour values in pomegranate beverage

Treatments	TSS (°B)	pH	TA (%)	Brix: Acid	Colour values		
					*L**	*a**	*b**
T_1	15.04	3.54	0.85	17.81	15.72	26.47	1.05
T_2	15.16	3.58	0.77	19.75	18.90	24.85	1.28
T_3	15.14	3.62	0.70	21.37	21.05	23.53	1.78
T_4	15.15	3.64	0.65	23.07	24.40	21.82	2.07
T_5	18.10	3.58	0.83	21.87	16.31	26.14	1.16
T_6	18.15	3.60	0.74	24.74	19.00	24.08	1.35
T_7	18.18	3.63	0.69	26.32	21.53	23.14	1.83
T_8	18.20	3.66	0.63	28.84	24.69	21.27	2.19
Mean	16.64	3.60	0.73	22.97	20.20	23.91	1.59
CD (p=0.01)	0.17	0.03	0.05	1.43	1.49	1.28	0.18

See Table 1 for treatment detail

100 per cent quinoa extract has a pH of 6.35. Acid gives the characteristic sourness to the product. Effect of quinoa extract on the titratable acidity of pomegranate beverages ranged between 0.63 and 0.85 per cent. Both in sugar 15º Brix and 18º Brix, titratable acidity decreased as the concentration of quinoa extract increased. This may be due to less acidity and more pH value of quinoa extract. The negative association with pH and acidity was observed. Islam et al (2014) also inferred that acidity and pH are inversely proportional to each other, as pH increases the concentration of hydrogen ion decreases. The maximum pH sample has minimum titratable acidity. Brix to acid ratio is often an indicator of acceptability than either sugar or acid alone (Jayasena and Cameron 2008). Among the different treatments, T_8 recorded significantly highest value for Brix to acid ratio (28.84).

***L*, a*,* and *b*colour values:** The Significant difference was recorded among the different treatments concerning the *L** value of pomegranate beverage by incorporation of quinoa extract (Table 3). *L** value was increased by incorporation of quinoa extract both in sugar 15º Brix and 18º Brix and ranged between 15.72 to 24.69. There was a decreased trend in *a** value of pomegranate beverage by incorporation of quinoa extract both in sugar 15º Brix and 18º Brix. Numerically, the highest *a** value was recorded in control I T_1 (Brix: 26.47). There were difference related to the *b** among the different treatments in pomegranate beverage by incorporation of quinoa extract. Significantly, the highest *b** value (2.19) was in T_8. The reduction of the redness value of beverages occur due to the natural pigment content of the quinoa, especially because has high phenolic components (Demir and Bilgicli 2021). The results are in line with Bhalerao et al (2020), where pomegranate juice was blended with different concentrations of muskmelon and amla juice, and found that, the decrease in the concentration of pomegranate juice increases the *l**, *b** values and decreases *a** values. Gonzalez-Molina et al (2009) reported that an increase in the concentration of lemon juice (25, 50 and 75%) reduced *a** values and increased the *b** values. Anthocyanins are responsible for the red colour of pomegranate juice. Anthocyanin is pH-dependent (the red flavylium is stable at low pH) and as the pH changes, the colour of the juice also changes (Choi et al 2002). The lighter colours of pomegranate beverage with quinoa extract were due to the higher pH which inhibits the coloured flavylium form of anthocyanins.

Phenols, DPPH free radical scavenging activity and tannin: The total phenol content of pomegranate beverages incorporated with quinoa extract ranged between 431.67 and 463.33 mg GAE/100 mL. The total phenol of pomegranate beverage has shown an increasing trend as the percentage of quinoa extract increased both in 15° brix and 18°brix beverages (Fig. 2). Compared to control II T_5 (100% Pomegranate juice + Sugar 18º Brix) there was increased in 31.66 mg GAE/100 mL of total phenols in T_4. The quinoa extract (20%) incorporated pomegranate beverage showed higher phenolic content because, quinoa is the major source of phenolic acids *viz*., vanillic (523.92 $\mu g g^{-1}$), coumaric (275 $\mu g\ g^{-1}$), 3, 4-Dihydroxybenzoic acid (275 $\mu g\ g^{-1}$), p-hydroxybenzoic acid (97 $\mu g\ g^{-1}$), gallic acid (320 $\mu g\ g^{-1}$) and caffic acid (6.31 $\mu g\ g^{-1}$) (Tang and Rong 2017). The results are in conformity with the findings of Demir and Kilinc (2017) who observed that the phenol content was increased significantly by the substitution of quinoa flour in cookies and also utilization of quinoa flour in gluten-free pasta formulation at a 30 per cent ratio increased the total phenol content compared to control (Demir and Bilgicli 2021).

Appropriate diets that include fruits, vegetables, whole grains and pseudo cereals may contribute to good health due to rich source of anti-oxidants. Among these foods, cereals and pseudo cereals play an important role (Shela et al 2008, Calderelli et al 2016). The antioxidant activity of pomegranate beverages by incorporation of quinoa extract ranged between 95.38 and 98.05 per cent (Table 4). Control II T_5 showed 2.67 per cent less antioxidant activity than the treatment T_4. The antioxidant activity of fruits and vegetables largely depends upon an abundance of individual antioxidants or the combined effect of antioxidants like phenolic compounds, ascorbic acid and anthocyanins (Rai et al 2011). Quinoa extract incorporated pomegranate

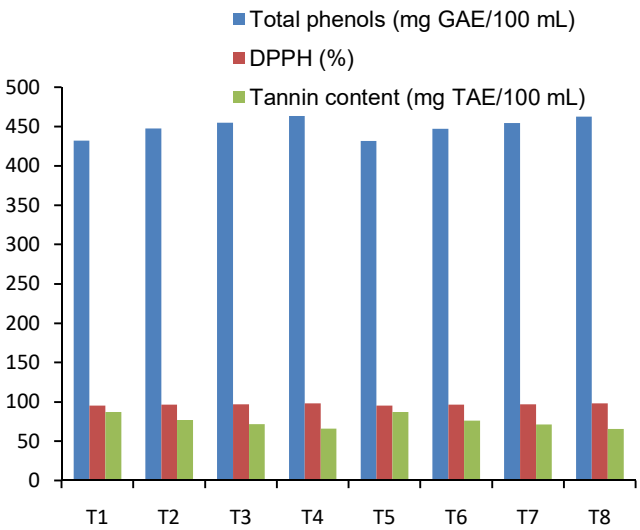

Fig. 2. Effect of incorporation of quinoa extract on total phenols antioxidant activity and tannin content in pomegranate beverage

Table 4. Effect of incorporation of quinoa extract on mineral contents in pomegranate beverage

Treatments	Potassium (mg/100 mL)	Phosphorous (mg/100 mL)	Calcium (mg/100 mL)	Magnesium (mg/100 mL)	Iron (mg/100 mL)	Zinc (mg/100 mL)
T_1	638.33	146.04	160.00	44.00	2.86	0.26
T_2	683.83	173.42	175.33	55.20	3.06	0.32
T_3	697.33	187.31	187.33	60.80	3.16	0.37
T_4	718.83	201.58	194.00	66.80	3.26	0.43
T_5	638.17	145.64	159.33	43.60	2.85	0.26
T_6	683.67	173.02	174.67	54.80	3.05	0.31
T_7	697.17	186.91	186.67	60.40	3.15	0.36
T_8	718.67	201.19	193.00	66.60	3.25	0.42
Mean	684.50	176.89	178.79	56.53	3.08	0.34
CD (p=0.01)	3.23	1.42	5.31	2.01	0.01	0.02

See Table 1 for treatment detail

beverages exhibited maximum antioxidant activity because quinoa contain compounds like polyphenols, phytosterols and flavonoids with possible nutraceutical benefits (Abugoch James 2009). In the same way, the addition of quinoa flour increases antioxidant activity in the bread as reported by Ballester-Sanchez et al (2019) and remarkable improvement in scavenging capacity was observed with increasing addition of quinoa flour *i.e.* 1.38-fold increase in DPPH radical scavenging capacity in wheat bread (Xu et al 2019). The total tannin content of pomegranate beverages by incorporation of quinoa extract showed a significant difference between the treatments (Fig. 2) and between 65.64 mg TAE/100 mL and 87.44 mg TAE/100 mL Treatment T_8 (80 % pomegranate juice + Sugar 15º Brix +20% quinoa extract) showed 21.80 mg TAE/100 mL less tannin content than the control I T_1 (100% ppomegranate juice + sugar 15º Brix). Pomegranate is also a rich source of hydrolyzable tannins. Upon adding different concentrations of quinoa extract to pomegranate juice, the tannin content of pomegranate beverage decreases with an increase in the percentage of quinoa extract. The quinoa seeds contain a less amount of tannins and adequate processing further reduce its content (Filho et al 2017). Same trend was observed in the Deepika and Panja (2017) where enrichment of aonla pulp with fruit pulp of mango, papaya, and jackfruit reduced the tannin content of the resultant fruit bars compared to that from pure aonla pulp, which is an indication in the reduction of astringency.

Minerals: Significant differences were observed among the treatments for potassium, phosphorous, calcium, magnesium, iron and zinc contents in pomegranate beverages incorporated with quinoa extract (Table 4). The highest amount of potassium (718.83 mg/100 mL), phosphorous (201.58 mg/100 mL), calcium (194 mg/100 mL), magnesium (66.80 mg/100 mL) content was in T_4(80% pomegranate juice + 20 % quinoa extract+ Sugar 15º Brix) and lowest amount of potassium (638.17 mg/100 mL), phosphorous (145.64 mg/100 mL), calcium (159.33 mg/100 mL), magnesium (43.60 mg/100 mL) content was in control II T_5 (100% ppomegranate juice +sugar 18º Brix). Highest content of minerals in quinoa incorporated pomegranate beverage may be due to quinoa is abundant in minerals such as calcium, iron, phosphorus, zinc and potassium and are reported to have more concentrations than most grain crops. Iron, calcium, and phosphorus levels are higher in quinoa than those of maize and barley (Arneja et al 2015). The present study is supported by Demir and Bilgicli (2021) where quinoa flours were replaced with rice: corn semolina blend at different (0–30%) ratios in gluten-free pasta formulation. The significant increment was observed in calcium, iron, potassium, magnesium, phosphorous and zinc content of the gluten-free pasta in addition to quinoa flour. Demir and Kilinc (2017) also observed that the potassium, magnesium, calcium, iron and zinc contents were increased as the concentration level of quinoa flour increased in the preparation of cookies.

CONCLUSION

Quinoa extract incorporated pomegranate beverage with combination of 80 % pomegranate juice + 20% quinoa extract+ sugar (15º Brix)had highest antioxidant activity, total phenols, total flavonoids and also addition of quinoa extract to pomegranate juice increased the mineral content such as potassium, phosphorous, calcium, magnesium, iron and zinc.

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Economic Analysis and Resource use Efficiency of Sunflower Cultivation in Haryana

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***Abstract*:** The present study was conducted during spring season of 2020-21 for determining the cost and returns of sunflower and its resource use efficiency in Kurukshetra district of Haryana. Multi-stage random sampling technique was employed for selection of 80 sunflower growers. The relevant primary data was mined from selected farmers through survey method. The total cost incurred in sunflower cultivation was ₹ 76297/ha and gross returns were ₹ 91526/ha thus reflecting net returns of ₹ 15229/ha. Moreover, the B-C ratio of 1.20 was realized which reflected the profitability of sunflower. Further, the Cobb-Douglas production function analysis revealed that value of R^2 was 0.76 and efficiency of resource use in sunflower exhibited increasing returns to scale which indicated under-utilization of the farm resources for sunflower cultivation. Seed exhibited the highest resource use efficiency while machine labour was found to be least efficient input.

***Keywords*:** B-C ratio, Net returns, Production function, Resource use efficiency, Sunflower

India is one of the world's leading producers of oilseeds (Lokesh and Dandoti 2017), producing a wide variety of crops such as soybean, rapeseed-mustard, groundnut, sesame, sunflower, castor, etc. The oilseed sector contributed significantly to the agricultural economy of the country providing a source of income for millions of farmers and supporting various downstream sectors (Narayan 2016, Sharma 2018, Satishkumar et al 2022). The total oilseeds production in India has increased from 18 to 35.90 million tonnes in last three decades reflecting the doubling of production. This increment in production is due to rise in both acreage (19.50%) and productivity (61.73%) during the same time period. Furthermore, this sector accounted for a considerable share of India's agricultural exports worth ₹ 83.10 billion in 2020-21. Even though India produces substantial quantities of oilseeds, it imports a significant amount of edible oils to meet domestic demand. India imported 14.2 million tonnes of edible oils worth ₹ 1415.32 billion in 2020-21 (RBI 2022).

Sunflower (*Helianthus annuus* L.) is an essential oilseed crop (Sunandini and Devi 2020) which plays a pivotal role in meeting out the demand of edibles oils in India (Ramamurthy et al 2022). The crop's prominence has increased due to the national emphasis on vegetable oil production and Technology mission on oilseeds launched in 1986 which subsequently restructured as Integrated Scheme of OilSeeds, Pulses, Oilpalm and Maize (ISOPOM) in 2004 (Reddy 2009, Reddy and Bantilan 2012). In India, the area under sunflower cultivation increased from 117 t ha in 1970-71 to 2668 t ha) in 1993-94, fluctuated until 2009-10, and thereafter declined significantly. In Haryana, the crop occupies an area of 12.29 t ha with total production of 24.63 thousand tonnes in 2020-21 (GoH 2022). Keeping in view the importance of crop, the present study was undertaken in order to figure out the returns and resource use efficiency of sunflower in the study area.

MATERIAL AND METHODS

Study area and design: The present study was conducted in Kurukshetra district of Haryana during 2020-21. The district is having assured irrigation facilities and various cropping systems like paddy-wheat, paddy-potato-sunflower, sugarcane-ratoon, etc. Multi-stage random sampling technique was employed for selection of the sampled farmers. Kurukshetra district was selected purposively at first stage of sampling based on area under sunflower cultivation in the state. At the second stage of sampling, two blocks i.e. Ladwa block and Shahbad block, were selected randomly. The random selection of two villages from each block was third stage of sampling. At last stage of sampling, 20 farmers from each village were selected randomly. Finally, 80 farmers were interacted through face-to-face approach in order to extract the pertinent information for addressing objectives of the study.

Data collection and analysis: The present investigation was based on primary data. Self-prepared and pre-tested

interview schedule was used for the collection of relevant information from sunflower growers related to their demographic characteristics, inputs used in sunflower cultivation, input-output prices, yield, returns etc. Simple descriptive analysis and budgeting techniques were used for drawing practical inferences.

Resource use efficiency: For determining the efficiency of resources used in the cultivation of sunflower, following Chand and Anoop (2022) and Guleria et al (2022), the Cobb-Douglas type of production function was used considering six explanatory variables in monetary terms and the following functional form was used:

$Y = aX_1^{b1}X_2^{b2}X_3^{b3}X_4^{b4}X_5^{b5}X_6^{b6}u$

This above functional form was analyzed using ordinary least square method after transforming into logarithmic form:

$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3 + b_4 \log X_4 + b_5 \log X_5 + b_6 \log X_6 + u$

Where, Y = Output value (₹/ha), a = Constant, X_1 = Seed (₹/ha), X_2 = Chemical fertilizers (₹/ha), X_3 = Plant protection chemicals (₹/ha), X_4 = Human labour (₹/ha), X_5 = Machine labour (₹/ha), X_6 = Irrigation (₹/ha), b_1, b_2 … b_6 = Regression coefficient of respective input X_i and u = Random error term

Statistical significance of the regression coefficients were tested using 't' test.

The resource use efficiency was computed by finding the difference between marginal value product (MVP) and marginal factor cost (MFC) for each input. MFC or P_i is the price of additional unit of input and MVP is calculated as:

MVP of $X_i = b_i (\overline{Y}/\overline{X}) Pi$

Where, b_i = regression coefficient of i^{th} input, $\overline{Y}$ = Geometric mean of output Y, $\overline{X}$ = Geometric mean of input X_i, P_i = Price of input X_i

The decision rules under MVP-MFC method are as follows: if MVP-MFC > 0 then it represents underutilization of farm resources; if MVP-MFC = 0 then it represents efficient utilization of farm resources; if MVP-MFC < 0 then it represents over utilization of farm resources.

RESULTS AND DISCUSSION

Demographic characteristics of the sample farmers: The demographic characteristics such as age composition, family size, farming experience and educational status, is shown in Table 1.

Cost and return structure of sunflower: The pertinent information with regard to various inputs used, output obtained and their prevailing market prices during 2020-21 was collected from sampled farmers of Kurukshetra district of Haryana in order to compute the cost and returns of sunflower (Table 2). The total cost incurred in cultivating sunflower was ₹ 76297/ha in the study area, out of which,

Table 1. Demographic characteristics of the sample farmers

Particulars	No. of respondents (N=80)	Per cent
Age (Year)		
Young (up to 35 years)	6	7.50
Middle (36 to 55 years)	60	75.00
Old (above 55 years)	14	17.50
Total	80	100.00
Family size (Member)		
Small (3-5)	26	32.50
Medium (6-8)	34	42.50
Large (Above 8)	20	25.00
Total	80	100.00
Farming experience (Year)		
Up to 10 years	8	10.00
11-20 years	62	77.50
Above 20 years	10	12.50
Total	80	100.00
Education		
Illiterate	20	25.00
Below matric	32	40.00
Matric / Sr. Secondary	24	30.00
Graduate / above	4	5.00
Total	80	100.00

Table 2. Cost of cultivation of sunflower in Kurukshetra district of Haryana (₹/ha)

Particulars	Quantity	Value	Percentage
Preparatory operation (No.)	5	9639	(12.64)
Sowing		2583	(3.38)
Seed (Kg)	4.22	2436	(3.19)
Chemical fertilizers (kg)	331.03	3832	(5.02)
Irrigation (No.)	7	2138	(2.81)
Inter-cultural operation (No.)	3	4828	(6.33)
Plant protection chemical		2038	(2.67)
Harvesting operation		12186	(15.97)
Miscellaneous		171	(0.22)
Interest on working capital @ 7% p.a		916	(1.20)
(A) Total variable cost		40767	(53.43)
Transportation cost		1834	(2.41)
Rental value of land		25542	(33.48)
Management charges @ 10%		4077	(5.34)
Risk charges @ 10%		4077	(5.34)
(B) Total fixed cost		35530	(46.57)
Total cost (A+B)		76297	(100.00)

Figures within parentheses indicates percentage to total cost

53.43 per cent was variable cost (₹ 40767/ha) and 46.57 per cent was fixed cost (₹ 35530/ha). The variable cost constituted highest share in total cost because operations like harvesting operation (₹ 12186/ha), preparatory operation (₹ 9639/ha), inter-cultural operation (₹ 4828/ha), etc. carried out in sunflower cultivation were costly and labour-intensive. In addition to this, chemical fertilizers, which costs near about ₹ 3832/ha further augmented the total variable cost. Among the fixed cost, rental value of land alone share a segment of 33.48 per cent (₹ 25542/ha) of total cost of cultivation due to high fertility of land along with assured irrigation water availability in the study area. The cost and returns obtained from sunflower cultivation in the study area exposed that the yield achieved from its cultivation was 17.63 quintals/ha with monetary values of ₹ 91526/ha (Table 3). As the total cost incurred in cultivating sunflower was ₹ 76297/ha, the net returns realized were ₹ 15229/ha. Moreover, the value of B-C ratio (1.20) indicated the economic viability of sunflower cultivation in the study area. Similar results of sunflower profitability were obtained by Suneetha and Illuru (2014) and Sonawane et al (2019). Further, similar findings were also described by Das and Rout (2018) on economic analysis of sunflower enterprise in western Odisha.

Resource use efficiency in sunflower cultivation: The production function analysis is a useful tool for allocating farm resources. The Cobb-Douglas type production function, as defined in the methodology, was used to determine the efficiency of each resource namely seed (X_1), chemical fertilizers (X_2), plant protection chemicals (X_3), human labour (X_4), machine labour (X_5) and irrigation (X_6). Table 4 displays the regression coefficient (b_i) of the production function, as well as its standard errors, t-value, coefficient of multiple determination (R^2) and returns to scale. The R^2 was 0.76 which indicated that 76 per cent of the variability in sunflower gross returns was determined by the variables in the model and the remaining unexplained variation (24%) might be ascribed to plethora of factors like sunflower variety/hybrid chosen, time of sowing, cultivation practices and varied agro-climatic conditions. Further, the production function analysis indicated that the regression coefficient of machine labour and human labour were found to be positive and significant at 5 and 10 per cent levels, respectively. This positive significance reflected that increase in machine labour (5%) and human labour (10%) would increase gross returns by 0.77 and 0.57 per cent, respectively thus indicating their contribution in sunflower cultivation. However, seed, chemical fertilizers, plant protection chemicals and irrigation had non-significant impact on sunflower returns. Moreover, the return to scale (1.38) implies increasing returns in the study area. These results were in conformity with the findings of Badar et al (2002), Sonawane et al (2019) and Suneetha and Illuru (2014).

For determining the efficiency of resource use in sunflower cultivation, the difference between marginal value product (MVP) and marginal factor cost (MFC) was calculated and significance test were applied (Table 5). The finding reveals that the difference between MVP and MFC was found to be positive for inputs namely, seed, human labour, machine labour and irrigation thus indicating underutilization of such inputs, which shows that there is enough possibility to increase the profits from cultivating sunflowers by increasing the use of these resources. However, the negative difference was obtained for chemical fertilizers and plant protection chemicals thus indicated that these inputs were over utilized. Further, seed exhibited the highest resource use efficiency as the difference between MVP and MFC for seed being closest to zero while machine labour was found to be least efficient resource. Similar kind of results was reported by Irugu et al (2017) in their study on resource use efficiency of sunflower in Kurnool district of Andhra Pradesh.

Table 3. Cost and returns from sunflower in Kurukshetra district of Haryana (₹/ha)

Particulars	Value
Total variable cost	40767
Total fixed cost	35530
Total cost	76297
Gross returns	91526
(a) Main product (17.63 Qtl.)	91526
Return over variable cost	50759
Net return	15229
Cost of production (₹/Qtl.)	4328
B:C ratio	1.20

Table 4. Regression coefficient and standard error of sunflower production

Variables	Regression coefficient (b_i)	Standard error (SE)	t-value
Intercept	-2.02	5.02	-0.40
Seed	-0.04^{NS}	0.25	0.11
Chemical fertilizers	-0.01^{NS}	0.04	0.31
Plant protection chemicals	0.04^{NS}	0.02	1.62
Human labour	0.57*	0.36	1.85
Machine labour	0.77**	0.35	2.20
Irrigation	0.05^{NS}	0.10	0.51
Returns to scale	1.38		
R^2	0.76		

** Significant at 5% level, * Significant at 10% level, NS: Non-significant

Table 5. Resource use efficiency in sunflower cultivation

Inputs	Seed	Chemical fertilizers	Plant protection chemicals	Human labour	Machine labour	Irrigation
MVP	1.37	0.50	1.92	2.70	7.92*	2.25
MFC or price	1.00	1.00	1.00	1.00	1.00	1.00
Difference	0.37@	-0.50	-0.92	1.70	6.92#	1.25
S.E. of MVP	9.18	1.63	1.18	1.72	3.60	4.39
t-value	0.04	-0.30	0.78	0.99	1.92	0.28

Minus sign in the row 'Difference' shows over utilization and positive value shows under utilization
#Least resource use efficiency, @Highest resource use efficiency, * Significant at 10% level

CONCLUSION

The results of the present study revealed that the socio-economic status of the respondents in the study area was moderate with better education and ample farming experience. The B-C ratio reflected the economic feasibility of sunflower cultivation in the region. The production function analysis indicated that seed was the most efficiently utilized resource whereas machine labour was found to be least efficiently utilized. Moreover, increasing returns to scale has also been observed. So, it can be concluded that sunflower cultivation is a profitable enterprise for fetching greater returns. Thus, its cultivation needs to be prioritised for massive seed production in order to meet out the demand of edible oils. Furthermore, inclusion of sunflower in the cropping system will also provide farmers an option of crop diversification from prevailing field crops and ample scope for sustaining agro-processing enterprises, which generate massive employment opportunities.

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Nutrient Degradability Evaluation of Complete Feed Pellets and Effect On Performance of Sirohi Goat

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***Abstract*:** In total, 16 different types of crop residue-based complete feed pellets were prepared by replacing paddy straw @ 50%, 75% and 100% with wheat straw, soybean straw, gram straw, *Cajanus cajan* straw, and groundnut straw from roughage portion by maintaining 60:40 roughage: concentrate ratio to study in *vitro* dry matter degradability and it's *in vitro* gas production. Gram straw-based complete feed pellet revealed significantly higher dry matter and crude protein degradability, while higher NDF degradability was reported in *Cajanus cajan* straw based complete feed pellets and higher IVGP in groundnut straw pellets. The gram straw based complete feed pellets was selected as a superior one on the basis of its better IVDMD. Subsequently for the in vivo study, twelve Sirohi adult goat were randomly selected and were fed for the 30 days following standard housing and management. The control group was fed with *ad lib* super napier hay and concentrate as per ICAR 2013, while treatment group was fed *ad lib* gram straw-based pellet. Significantly better growth performance, nutrient utilization, rumen fermentation and low cost of production was in goats of treatment group with non-significant difference in hematological parameters, body condition score and rumen motility. It can be concluded that gram straw based complete feed pellets had more degradable nutrient and improved performance of goat.

Keywords: Crop residues, Complete feed, Nutrient utilization and goat

In order to feed livestock, non-competitive and unconventional agricultural wastes are used since there is a shortage of green fodder and a rising demand for grains for human consumption. The majority of India's dry fodder needs are satisfied by crop residues. But these crop residues are rich in fibre and low in protein, vitamins and minerals and therefore they have low palatability and digestibility. Hence, their use in animal ration is limited (Patil and Patil 2020, Raju et al 2021). To overcome the shortage of green and dry fodder and to make crop residues more palatable and nourishing, processing is necessary and this will be possible by the adoption of complete feed systems. For early evaluation of nutritive value of different crop residue based complete feed pellets, *in vitro* evaluation method was used to evaluate *in vitro* DM, CP and NDF degradability and *in vitro* gas production of different crop residue based complete feed pellets. The effect of superior crop residue based complete feed pellets (based on IVDMD%) on the performance of Sirohi goat was evaluated.

MATERIAL AND METHODS

In total, 16 different types of crop residue-based complete feed pellets were prepared by replacing paddy straw @ 50, 75 and 100% with wheat straw, soybean straw, gram straw, *Cajanus cajan* straw, and groundnut straw from roughage portion by maintaining 60:40 roughage to concentrate ratio. The composition of concentrate mixture used in complete feed pellets is given in Table 1. Representative samples from the different complete feed pellets were analysed for various proximate principles (moisture, CP, EE, CF, total ash, and acid insoluble ash) as per AOAC (2007), and NDF and ADF were estimated by Van Soest method (1991).

***In vitro* study:** Rumen liquor was collected from the goat 3-4 h post-feeding and strained through four layers of muslin cloth. This procedure was carried out by taking dried and ground (particle size < 1mm) each straw-based complete feed pellets as a substrate in a 100ml conical flask for the first stage *in vitro* method (Tilley and Terry, 1963). Similarly, dried residue of other sets of samples were used to estimate IVCPD and IVNDFD percent by estimating CP and NDF by standard procedures. *In vitro* gas production was carried out using the Hohenheim gas test according to procedures of Menke and Stein-gass (1988) described by Santoso et al. (2018). Recorded the gas volume after 2, 4, 8, 12 and 24 h of incubation.

***In vivo* trial: Selection and management of goats:** Twelve healthy adult Sirohi goats of approximately similar body weight (19.08±0.18 Kg) were divided into two groups with six

goats each and reared under the same intensive management system. The goats in the control group (group I) were fed *ad lib* super napier hay and 400 g concentrate mixture to satisfy the nutrient requirement as per ICAR 2013. Goats in the treatment group (group II) were fed *ad lib* complete feed pellets containing 60%-gram straw and a concentrate mixture of 40%.

Estimation of dry matter intake, body weight gain, BCS and FCR: Goat's initial and weekly live body weights were recorded. Daily feed intake was recorded by subtracting the feed left over from the feed offered to each goat. Initial body condition score and body condition score every fortnight was recorded. Scoring is done by using the hand to feel for the fullness of muscling and fat cover over and at the lumbar region, brisket region, ribs and into the vertebrae in the loin region. FCR was calculated by dividing weight gain by feed intake.

Metabolic trial and N, Ca and P balance: The metabolic trial was conducted with all 12 goats. A 21-day preliminary and two-day adoption period was followed by a four-day collection period. The goats were kept in individual metabolic cages having provisions for feeding and watering. The goats were offered respective rations and daily dry matter intake, feed refusal, total faeces and urine passed were recorded and collected individually. The samples of super napier hay, concentrate mixture, gram straw-based complete feed pellets and dried faeces were analyzed for proximate analysis , Ca and P (AOAC, 2007), and ADF and NDF by Van Soest (1991). Urine was analyzed for nitrogen as per AOAC (2007).

Rumen liquor profile: The sucked fluid was filtered through the cheese cloth and pH was immediately measured. The filtered rumen liquor was immediately taken for digestion to estimate total nitrogen. 15 ml of rumen liquor was frozen and stored at -20 ^{0}C for determination of TVFA. TVFA was determined using the Markham apparatus as described by Bernett and Reid (1957). The total nitrogen was analyzed as per AOAC (2007). The total bacterial and protozoan count was carried out by the direct method (Smith and Baker 1944).

Body condition score: Body condition score evaluated in the score of 1 to 5 (Canadian scale) where 1 is emaciated and 5 is obese (Lowman et al 1976).

Ruminal motility: The ruminal motility of goats in the control and treatment group was recorded weekly by auscultation of the rumen from the left paralumbar fossa.

Hemato-biochemical parameters: Blood samples were subjected to the haematological analysis (Hb (g/dl), PCV (%), TEC (x 10^{6}/µl), and TLC (x 10^{3}/µl)) and the serum was separated as per the standard procedure and was analyzed in a semi-auto analyzer using diagnostic kits for various biochemical parameters.

Cost of production: The cost of each experimental diet was calculated considering the prevailing market price of individual feed ingredients and supplements during the experiment. The cost per kg live body weight of goat reared under different feeding regimens was calculated based on feed consumption data for 0-28 days.

Statistical analysis: For interpretation of the results, the data of the *in vitro* study was analysed by Duncan's Multiple Range Test (DMRT). Used IBM SPSS Statistics 25 software for analysing the data .

RESULTS AND DISCUSSION

Chemical composition of feedstuffs: The chemical composition of different crop residue based complete feed pellets is mentioned in Table 1 to 3. The chemical composition of super napier hay, concentrate mixture and gram straw-based complete feed pellets is given in Table 10.

***In vitro* dry matter degradability:** The highly significant difference was observed in the *in vitro* dry matter degradability of different crop residue-based complete feed pellets with the different levels of replacement as well as within each level of replacement among various types of crop residue based complete feed pellets (Table 4). Significantly higher IVDMD percent was in gram straw based-complete feed pellets followed by *Cajanus cajan* straw, soybean straw, groundnut straw, and wheat straw-based complete feed pellets at 50, 75 and 100% replacement levels. Among the different crop residue-based complete feed pellets significantly higher IVDMD was in the 100% replacement group followed by 75, 50 and 0% replacement groups except IVDMD percent of complete feed pellets having wheat and groundnut straw in the 75 and 100% replacement groups, where a non-significant difference was observed between each other. The IVDMD percent in fully paddy straw-based complete feed pellets and 50% wheat straw-based complete feed pellets showed a non-significant difference. These findings in the present experiment indicated that 75% replacement of paddy straw with wheat straw and 100% replacement of paddy straw with *Cajanus cajan* straw, groundnut straw, soybean straw, and gram straw in the complete feed pellets resulted in better *in vitro* dry matter degradability of crop residue-based complete feed pellets. The significantly higher percent IVDMD was in 100%-gram straw-based complete feed pellets in the present study with all three roughages to concentrate ratios might be due to the higher NFE and lower CF concentration in the gram straw-based complete feed. Chauhan et al (2017) also reported significantly higher IVDMD percent for a 100%-gram straw-based total mixed ration with roughage to concentrate ratio of 55:45.

Table 1. Chemical composition of different crop residue-based complete feed pellets at 50% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	DM (%)	CP (%)	CF (%)	EE (%)	Total Ash (%)	NFE (%)	AIA (%)	NDF (%)	ADF (%)	ADL (%)
Paddy straw (50%) +Wheat straw (50%) based complete feed pellets	92.18	10.58	28.09	1.50	10.45	48.57	2.45	57.69	40.82	9.96
Paddy straw (50%) + *Cajanus cajan* straw (50%) based complete feed pellets	92.23	11.66	26.04	1.60	10.28	50.42	2.14	57.85	39.70	8.73
-Paddy straw (50%) +Groundnut straw (50%) based complete feed pellets	92.20	11.76	26.87	1.74	9.65	49.98	2.15	51.22	36.78	8.61
Paddy straw (50%) + Soybean straw (50%) based complete feed pellets	91.46	11.53	27.36	1.26	9.96	49.89	2.33	54.46	38.82	8.71
Paddy straw (50%) + Gram straw (50%) based complete feed pellets	92.16	11.28	25.16	1.98	10.09	51.49	2.21	54.07	37.70	8.66

Table 2. Chemical composition of different crop residue-based complete feed pellets at 75% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	DM (%)	CP (%)	CF (%)	EE (%)	Total Ash (%)	NFE (%)	AIA (%)	NDF (%)	ADF (%)	ADL (%)
Paddy straw (25%) + Wheat straw (75%) based complete feed pellets	91.86	10.52	28.18	1.54	10.49	49.27	2.40	56.18	40.28	9.79
Paddy straw (25%) + *Cajanus cajan* straw (75%) based complete feed pellets	91.56	11.78	25.52	1.64	10.14	50.92	2.05	56.77	39.20	7.91
Paddy straw (25%) + Groundnut straw (75%) based complete feed pellets	91.60	11.82	26.81	1.81	9.47	50.09	2.52	47.70	32.30	7.75
Paddy straw (25%) + Soybean straw (75%) based complete feed pellets	91.95	11.67	27.08	1.36	9.85	50.04	2.29	52.68	38.32	7.85
Paddy straw (25%) + Gram straw (75%) based complete feed pellets	92.21	11.38	23.64	2.06	9.96	52.96	2.13	52.42	34.40	7.79

Table 3. Chemical composition of different crop residue-based complete feed pellets at 100% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	DM (%)	CP (%)	CF (%)	EE (%)	Total Ash (%)	NFE (%)	AIA (%)	NDF (%)	ADF (%)	ADL (%)
Paddy straw (100%) based complete feed pellets	90.18	10.49	27.96	1.56	11.61	48.38	2.54	58.48	42.70	10.39
Wheat straw (100%) based complete feed pellets	90.81	10.74	28.32	1.48	9.50	49.96	2.34	56.90	39.80	9.60
Cajanus cajan straw (100%) based complete feed pellets	90.17	12.71	24.12	1.67	8.95	52.55	1.76	57.10	38.66	7.11
Groundnut straw (100%) based complete feed pellets	91.74	12.83	25.82	1.78	7.92	51.65	2.57	43.70	30.00	6.84
Soybean straw (100%) based complete feed pellets	91.45	12.62	26.80	1.34	8.41	50.83	2.05	50.48	34.80	7.01
Gram straw (100%) based complete feed pellets	90.27	12.07	22.31	2.06	8.57	54.99	1.91	50.65	31.90	6.96

***In vitro* crude protein degradability:** The highly significant difference was observed in the *in vitro* crude protein degradability of different crop residue-based complete feed pellets with the different levels of replacement as well as within each level of replacement among various types of crop residue based complete feed pellets (Table 5). There was significantly higher percent IVCPD was observed in gram straw-based complete feed pellets followed by *Cajanus cajan* straw, soybean straw, groundnut straw, and wheat straw-based complete feed pellets at 50, 75 and 100% replacement levels except *Cajanus cajan* straw and soybean straw-based complete feed pellets at 75 and 100% replacement levels, which showed a non-significant difference between each other. However, the crop residue-based complete feed pellets in the 100% replacement group showed significantly greater percent IVCPD followed by 75 and 50 and 0% replacement group irrespective of variation in the straws in the complete feed pellets with few exceptions. But with IVCPD of wheat straw-based complete feed pellets, significantly greater percent IVCPD was observed in 100% replacement group followed by 0, 75 and 50% replacement levels. Further, the percent IVCPD of 50% groundnut straw-based complete feed pellets and sole paddy straw-based complete feed pellets revealed a non-significant difference between each other. Similarly, the percent IVCPD of 50% soybean straw-based complete feed pellets did not reveal significant difference with percent IVCPD of 100% paddy straw-based complete feed pellets. These findings indicated that 100% replacement of paddy straw with other straws in the complete feed pellets showed better *in vitro* crude protein degradability. However, 100% paddy straw-based complete feed pellets showed significantly better *in vitro* crude protein degradability than 50 and 75% wheat straw-based complete feed pellets. The availability of greater degradable protein and lower crude fibre in gram straw-based complete feed pellets may account for the significantly higher percent IVCPD. Konka et al (2015) found higher IVCPD in a complete ration containing maize stover than in a complete ration containing black gram straw and red gram straw.

Table 4. *In vitro* dry matter degradability (%) of crop residue-based complete feed pellets with roughage to concentrate in ratio of 60:40

Feed regime	Groups				Significance
	I Replacement of paddy straw 0%	II Replacement of paddy straw 50%	III Replacement of paddy straw 75%	IV Replacement of paddy straw 100%	
Wheat straw-based complete pellets	45.55^{aB}±1.01	45.88^{eB}±0.84	47.68^{eA}±0.49	47.78^{eA}±0.71	**
Cajanus cajan straw-based complete pellets	45.55^{aD}±1.01	54.92^{bC}±0.74	58.13^{bB}±0.36	61.63^{bA}±0.72	**
Groundnut straw-based complete pellets	45.55^{aC}±1.01	50.87^{dB}±0.15	56.28^{dA}±0.65	56.23^{dA}±0.46	**
Soybean straw-based complete pellets	45.55^{aD}±1.01	52.64^{cC}±0.33	57.31^{cB}±0.23	60.25^{cA}±0.88	**
Gram straw-based complete pellets	45.55^{aD}±1.01	55.11^{aC}±0.94	59.24^{aB}±0.26	64.37^{aA}±0.51	**
Significance	**	**	**	**	

1. For various replacement interpretations, the data may be read row wise, means bearing different superscripts (A, B, C, D) differ significantly. ** P < 0.01.
2. For interpretations in groups on various straw inclusion, the data may be read column wise, means bearing different superscripts (a, b, c, d, e) differ significantly. ** P < 0.01.

Table 5. *In vitro* crude protein degradability (%) of crop residue-based complete feed pellets with roughage to concentrate in ratio of 60:40

Feed regime	Groups				Significance
	I Replacement of paddy straw 0%	II Replacement of paddy straw 50%	III Replacement of paddy straw 75%	IV Replacement of paddy straw 100%	
Wheat straw-based complete pellets	54.87^{bB}±1.09	53.76^{dC}±0.41	54.07^{dBC}±0.13	56.22^{dA}±0.78	**
Cajanus cajan straw-based complete pellets	54.87^{aD}±1.09	57.42^{bC}±1.35	60.75^{bB}±0.50	64.15^{bA}±0.29	**
Groundnut straw-based complete pellets	54.87^{aC}±1.09	54.09^{dC}±0.51	58.00^{cB}±0.53	60.31^{bcA}±0.87	**
Soybean straw-based complete pellets	54.87^{aC}±1.09	55.06^{cC}±1.16	61.43^{bB}±0.33	63.41^{bA}±0.43	**
Gram straw-based complete pellets	54.87^{aD}±1.09	62.19^{aC}±0.99	63.19^{aB}±0.41	66.32^{aA}±0.22	**
Significance	**	**	**	**	

See Table 4 for details

***In vitro* neutral detergent fibre degradability:** The *in vitro* neutral detergent fibre degradability of different crop residue-based complete feed pellets with the different levels of replacement as well as within each level of replacement among various types of crop residue-based complete feed pellets differed significantly with complete feed pellets. The with *Cajanus cajan* straw had a significantly higher IVNDFD percent followed by gram straw, soybean straw, groundnut straw, and wheat straw-based complete feed pellets irrespective of different levels of replacement of paddy straw (Table 6). Among various levels of replacement i.e., 0, 50, 75 and 100%, significantly higher IVNDFD percent was or soybean straw and gram straw-based complete feed pellets with 100% replacement group followed by 75, 50 and 0% replacement groups. Among *Cajanus cajan* straw-based complete feed pellets, significantly higher IVNDFD percent was observed at 100 as well as 75% replacement levels followed by 50 and 0% replacement levels with a non-significant difference between the IVNDFD percent of 75 and 100% *Cajanus cajan* straw-based complete feed pellets. Among the complete feed pellets with wheat straw, significantly higher IVNDFD percent was at 100% replacement levels followed by 75 and 50 as well as 0% replacement levels with a non-significant difference in IVNDFD percent between 0 and 50% replacement levels. In IVNDFD percent of groundnut straw-based complete feed pellets, significantly higher IVNDFD percent was observed at 100% replacement level followed by 75 as well as 50 and 0% replacement levels. The findings in the present experiment suggest that 100% replacement of paddy straw with wheat straw, *Cajanus cajan* straw, soybean straw, groundnut straw, and gram straw in the complete feed pellets resulted in better *in vitro* neutral detergent fibre degradability. Further, the 0% replacement of paddy straw-based complete feed pellets had similar *in vitro* neutral detergent fibre degradability to that of 50% wheat straw-based complete feed pellets. When the complete feed contains roughage and concentrate in proper proportion, in such cases ruminal pH is not reduced drastically and the pH is maintained within normal physiological range, which might have favoured for microbial growth of fibre degrading bacteria. Similarly, Venkateswarlu et al (2013) also reported higher degradability of NDF for complete ration with black gram straw than complete ration with red gram straw.

***In vitro* gas production (IVGP):** The groundnut straw-based complete feed pellets revealed significantly higher IVGP (ml/200mg) at 2, 4, 8, 12 and 24 hr of incubation followed by soybean straw, gram straw, wheat straw and *Cajanus cajan* straw-based complete feed pellets irrespective of roughage to concentrate ratios (70:30, 60:40 and 50:50) and level of replacement (50, 75 and 100%) (Table 7 to 9). Regardless of roughage to concentrate ratio or level of replacement, the 12-24 hr incubation time resulted in significantly higher IVGP (ml/200mg) than the 8-12 hr, 4-8 hr, 2-4 hr, and 0-2 hr incubation periods. There was a decreasing trend in IVGP from 12-24 hr of incubation to 0-2 hr of incubation. Among the different crop residue-based complete feed pellets with 50, 75 and 100% replacement groups, in general higher *in vitro* gas production was observed for crop residue-based complete feed pellets in the 100% replacement group followed by 75 and 50% replacement groups. The comparatively lower IVGP of the crop residue-based complete feed pellets in the 50 and 75% replacement groups might be due to the mixing of paddy straw having high NDF, total ash and lignin content in the complete feed pellets. In the present investigation, significantly greater IVGP for groundnut straw-based complete feed pellets was might be due comparatively low NDF, ADF, ash, and ADL content than the other crop-residue-based complete feed pellets. The higher values of IVGP for groundnut straw-based complete

Table 6. *In vitro* neutral detergent fibre degradability (%) of crop residue-based complete feed pellets with roughage to concentrate in ratio of 60:40

Feed regime	Groups				Significance
	I Replacement of paddy straw 0%	II Replacement of paddy straw 50%	III Replacement of paddy straw 75%	IV Replacement of paddy straw 100%	
Wheat straw-based complete pellets	51.95^{aC}±0.32	51.43^{dC}±0.10	53.57^{eB}±0.27	55.09^{eA}±0.18	**
Cajanus cajan straw-based complete pellets	51.95^{aC}±0.32	63.34^{aB}±0.24	63.69^{aA}±0.11	64.05^{aA}±0.09	**
Groundnut straw-based complete pellets	51.95^{aC}±0.32	56.09^{cdB}±0.32	56.04^{dB}±0.27	56.63^{dA}±0.07	**
Soybean straw-based complete pellets	51.95^{aD}±0.32	56.42^{cC}±0.23	58.11^{cB}±0.07	60.46^{cA}±0.13	**
Gram straw-based complete pellets	51.95^{aD}±0.32	60.99^{bC}±0.33	62.13^{bB}±0.13	63.08^{bA}±0.05	**
Significance	**	**	**	**	

See Table 4 for details

Table 7. *In vitro* gas production (IVGP) (ml/200mg) of crop residue-based complete feed pellets at 50% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	*In vitro* gas production at different hrs (ml/200mg)					Significance
	2 hr	4 hr	8 hr	12 hr	24 hr	
Paddy straw (50%) + Wheat straw (50%)-based complete pellets	5.67^{dE}±0.58	11.33^{dD}±0.58	18.67^{dC}±0.58	24.67^{dB}±0.58	35.67^{dA}±0.58	**
Paddy straw (50%) + *Cajanus cajan* straw (50%)-based complete pellets	5.00^{eE}±0.00	9.33^{eD}±0.58	18.33^{eC}±0.58	23.33^{eB}±0.58	35.33^{eA}±0.58	**
Paddy straw (50%) + Groundnut straw (50%)-based complete pellets	11.33^{aE}±0.58	19.33^{aD}±0.58	28.67^{aC}±0.58	36.33^{aB}±0.58	48.33^{aA}±0.58	**
Paddy straw (50%) + Soybean straw (50%)-based complete pellets	8.00^{bE}±0.00	14.00^{bD}±0.00	21.33^{bC}±0.58	28.00^{bB}±0.00	37.67^{bA}±0.58	**
Paddy straw (50%) + Gram straw (50%)-based complete pellets	7.33^{cE}±0.58	13.33^{cD}±0.58	20.67^{cC}±0.58	25.33^{cB}±0.58	36.33^{cA}±0.58	**
Significance	**	**	**	**	**	

See Table 4 for details

Table 8. *In vitro* gas production (IVGP) (ml/200mg) of crop residue-based complete feed pellets at 75% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	*In vitro* gas production at different hrs (ml/200mg)					Significance
	2 hr	4 hr	8 hr	12 hr	24 hr	
Paddy straw (25%) + Wheat straw (75%)-based complete pellets	6.33^{dE}±0.58	11.67^{dD}±0.58	18.67^{dC}±0.58	25.67^{dB}±0.58	36.33^{dA}±0.58	**
Paddy straw (25%) + *Cajanus cajan* straw (75%)-based complete pellets	5.33^{eE}±0.58	9.67^{eD}±0.58	14.00^{eC}±0.00	23.67^{eB}±0.58	35.67^{eA}±0.58	**
Paddy straw (25%) + Groundnut straw (75%)-based complete pellets	11.67^{aE}±0.58	19.67^{aD}±0.58	29.67^{aC}±0.58	37.67^{aB}±0.58	50.33^{aA}±0.58	**
Paddy straw (25%) + Soybean straw (75%)-based complete pellets	8.67^{bE}±0.58	14.33^{bD}±0.58	22.00^{bC}±0.00	30.67^{bB}±0.58	40.67^{bA}±0.58	**
Paddy straw (25%) + Gram straw (75%)-based complete pellets	7.67^{cE}±0.58	13.33^{cD}±0.58	21.67^{cC}±0.58	28.67^{cB}±0.58	39.67^{cA}±0.58	**
Significance	**	**	**	**	**	

See Table 4 for details

Table 9. *In vitro* gas production (IVGP) (ml/200mg) of crop residue-based complete feed pellets at 100% replacement level with roughage to concentrate in ratio of 60:40

Feed regime	*In vitro* gas production at different hrs (ml/200mg)					Significance
	2 hr	4 hr	8 hr	12 hr	24 hr	
Paddy straw (100%)-based complete pellets	4.33^{fE}±0.58	7.67^{fD}±0.58	14.67^{fC}±0.58	21.33^{fB}±0.58	34.33^{fA}±0.58	**
Wheat straw (100%)-based complete pellets	6.67^{dE}±0.58	12.33^{dD}±0.58	21.67^{dC}±0.58	29.67^{dB}±0.58	39.67^{dA}±0.58	**
Cajanus cajan straw (100%)-based complete pellets	6.33^{eE}±0.58	10.33^{eD}±0.58	19.67^{eC}±0.58	27.67^{eB}±0.58	38.67^{eA}±0.58	**
Groundnut straw (100%)-based complete pellets	12.67^{aE}±0.58	20.67^{aD}±0.58	31.33^{aC}±0.58	39.67^{aB}±0.58	53.67^{aA}±0.58	**
Soybean straw (100%)-based complete pellets	9.33^{bE}±0.58	16.33^{bD}±0.58	23.33^{bC}±0.58	32.33^{bB}±0.58	43.67^{bA}±0.58	**
Gram straw (100%)-based complete pellets	8.00^{cE}±0.00	14.33^{cD}±0.58	22.00^{cC}±0.00	30.00^{cB}±0.00	41.33^{cA}±1.15	**
Significance	**	**	**	**	**	

See Table 4 for details

feed pellets might indicate a better nutrient availability for rumen microorganisms. The gas production trend in the current study revealed that increasing the quantities of NDF, ADF, ash, and lignin in the complete feed pellets lowered *in vitro* gas production. Kuliv and Kafilzadeh (2015) reported a positive CP correlation and negative NDF and ADF correlation with gas production and which agrees with the results found in the present investigation.

Daily dry matter intake: There was an increasing trend of dry matter intake from I to the IV week of the experiment in both control and treatment groups (Table 11). The DMI has increased successively due to increased body weights every week to fulfil the requirement. The highest daily dry matter intake was noticed during the IV week of the experiment and which was 856.88g in the control group and 1174.83g in the treatment group. The daily DMI in goats during the study period was significantly higher in the treatment group fed gram straw-based complete feed pellets than in the control group. DMI of crop residue-based complete feed pellets was higher due to more acceptability of complete feed in processed form. Grinding crop residues reduces particle size and pelleting with a concentrate mixture leads to lower bulk density. Therefore, to fulfil the bulk requirements, the DMI intake of complete feed could be improved (Nagalakshmi and Reddy, 2011). Higher DMI of crop residue-based complete processed feed was also reported by Rekhate et al (2008) in calves and Nagalakshmi and Reddy (2011) in lambs. Sihag et al (2008) reported higher DMI in lambs fed black gram-based pelleted complete feed and gram-based pelleted complete feed than the conventional ration.

Table 10. Chemical composition of concentrate mixture, super napier hay and gram straw-based complete feed pellets

Nutrients (%)	Concentrate mixture	Super napier hay	Gram straw based complete feed pellets (R:C=60:40)
Dry matter	91.26	89.38	90.67
Crude Protein	21.78	8.07	12.11
Ether extract	3.14	1.69	1.0
Crude fibre	9.0	37.6	22.42
Total ash	9.04	6.98	9.27
Nitrogen free extract	56.93	45.66	54.4
NDF	23.01	68.41	51.6
ADF	11.04	39.3	31.9
ADL	3.16	6.91	8.26
Hemicellulose	11.97	29.11	19.7
Cellulose	7.88	32.39	23.64
Calcium	0.82	0.48	0.89
Phosphorus	0.89	0.17	0.45

R: C=Roughage to concentrate ratio

Table 11. Performance parameters of goats in control and treatment groups

Sr. No.	Parameters	I week	II week	III week	IV week	Significance
Daily dry matter intake (g)	Control	779.49±26.84^{b}	811.56±12.29^{b}	845.60±7.14^{b}	856.88±2.43^{b}	0.01**
	Treatment	959.71±9.55^{a}	1061.26±15.41^{a}	1169.32±2.33^{a}	1174.83±2.57^{a}	
Average weekly body weights	Control	19.65±0.21^{b}	20.28±0.21^{b}	20.96±0.20^{b}	21.70±0.23^{b}	0.01**
	Treatment	20.19±0.22^{a}	21.36±0.20^{a}	22.55±0.20^{a}	23.77±0.21^{a}	
Daily body weight gain (g)	Control	83.81±5.24^{b}	90.48±1.46^{b}	97.38±8.20^{b}	106.19±7.32^{b}	0.01**
	Treatment	157.38±12.14^{a}	166.91±12.24^{a}	169.52±8.93^{a}	174.05±5.53^{a}	
FCR	Control	10.42±0.95^{a}	9.97±0.29^{a}	9.71±0.87^{a}	9.04±0.64^{a}	0.01**
	Treatment	6.76±0.90^{b}	7.05±0.83^{b}	7.63±0.40^{b}	7.45±0.24^{b}	
	Treatment	1	1	1	1	
Fortnightly Body condition score	Control	2.67±0.26		2.83±0.41		NS
	Treatment	2.83±0.26		3.08±0.38		

NS-Non-significant, Means bearing different superscripts in columns differ significantly (P < 0.01) **

Weekly body weights and daily weight gain: The significant difference in the average weekly body weights of goats were between the control and treatment groups during the experiment. During the complete experimental period, significant difference in average daily weight gain was between the control and treatment groups. Significantly higher daily body weight gain was in goats in the treatment group than in the goats in the control group. The highest daily weight gain in the goats of the control group was 106.19 g, whereas, 174.05 g daily body weight gain in the goats of the treatment group. The highest daily weight gain was during the fourth week of the study. The higher DMI and nutrient digestibility in the treatment group might have resulted in higher body weight gain in goats of the treatment group.) Venkateswarlu et al (2013) and Islam et al (2017) also reported a significant effect of feeding crop residue-based complete ration on growth rate than the traditional ration.

Feed conversion ratio (FCR): The highly significant difference in the FCR of goats between the groups was observed during the experimental period. The FCR in the control group was in decreasing trend from the I week to the IV week of the experiment, whereas no particular trend for FCR was observed in the treatment group. The significantly better FCR of goats in the treatment group might be due to the better utilization of nutrients in goats of the treatment group than the control group. Proportionate intake of roughage and concentrate through complete feed pellets gives a better rumen environment that stimulates the better utilization of nutrients (Dhuria et al 2009). Similarly, Islam et al (2017) reported a better feed conversion ratio in sheep fed TMR in pelleted form than TMR in loose form. Improved FCR on feeding crop residue-based complete feed was also reported by earliest scientist (Seshaiah et al 2013, Rashid et al 2016, Ahmed et al 2021).

Body condition score: The fortnightly body condition score of goats was non-significant between the groups. Though there was a slight increase in body condition score during I and II fortnight of the study, the difference was statistically non-significant. Slight improvement in body condition score in the treatment group than the control group might be due to more body weight gain in goats of the treatment group. Improved body condition score on feeding crop residue-based complete feed was reported by Ahmed et al (2021), whereas Mishra et al (2013) observed better body condition score in Malpura sheep on utilization of fallen tree leaves up to 20% in complete feed blocks and decreased BCS on 30% inclusion level of fallen tree leaves in complete feed block.

Nutrient utilization: The highly significant difference in the digestibility of DM, CP, CF, EE, NFE, ADF, NDF, hemicellulose and cellulose was observed between the groups (Table 12). Significantly higher digestibility of nutrients was found in the goats of the treatment group fed gram straw-based complete feed pellets than in the control group, indicating the better utilization of gram straw by the goats in complete feed form. The better utilization of nutrients from the complete feed pellets might be due to a uniform supply of nutrients at regular intervals, which helps maintain a steady and healthy rumen environment. Besides, the activities of different ruminal enzymes responsible for fibre degradation have been reported to be higher in animals fed complete ration as compared to animals fed conventional ration (Gupta et al 2006). Earlier scientist also found higher nutrient digestibility in animals fed complete rations in pelleted or block form than the conventional ration (Gupta et al 2006, Nagalakshmi and Reddy 2012, Kishore et al 2014, Mudgal et al 2014, Rashid et al (2016). The higher bacterial activities in goat's rumen on gram straw-based complete feed pellets may be attributed to its better CP and other nutrient degradability (Singh and Kundu 2011).

Nitrogen, calcium and phosphorus balance: The nitrogen, Ca and P intake, nitrogen, Ca and P excretion in faces and urine, as well as nitrogen, Ca and P retention (gm/head/day) in goats were significantly higher in the goats of the treatment group than in the control group (Table 13). The comparatively higher nitrogen, Ca and P retention in the treatment group was due to better nitrogen utilization by the microbes with comparatively more nitrogen intake. Xia et al. (2018) reported a positive effect of higher protein intake on nitrogen intake, excretion and balance in bulls fed a diet with high crude protein. Venkateswarlu et al (2013) also observed positive calcium and phosphorus balance in buffalo bulls fed jowar straw, maize stover, red gram straw and black gram straw-based complete feeds with roughage to concentrate ratio of 60:40.

Table 12. Nutrient utilization of goats in control and treatment groups

Nutrient	Digestibility %		Significance
	Control	Treatment	
Dry matter	60.33±0.27^{b}	65.47±0.49^{a}	0.01 **
Crude protein	63.69±0.45^{b}	67.09±0.43^{a}	0.01 **
Crude fibre	59.45±0.40^{b}	60.99±0.61^{a}	0.05 *
Ether extract	70.00±0.70^{b}	73.80±0.73^{a}	0.01 **
Nitrogen free extract (NFE)	67.11±0.99^{b}	69.71±0.94^{a}	0.01 **
NDF	61.49±0.31^{b}	64.07±0.47^{a}	0.01 **
ADF	53.42±0.44^{b}	54.93±0.47^{a}	0.01 **
Hemicellulose	71.62±0.22^{b}	78.92±0.70^{a}	0.01 **
Cellulose	64.21±0.66^{b}	71.54±1.07^{a}	0.01 **

Means bearing different superscripts in rows differ significantly (P < 0.01) **

Table 13. Nitrogen, Calcium and phosphorous balance in goats fed super napier hay and concentrate mixture or gram straw based-complete feed pellets

Particulars	Groups		Significance
	Control	Treatment	
Nitrogen (g/day)			
Intake (g)	19.06±0.70[b]	22.85±0.70[a]	0.01**
Faecal outgo (g)	6.92±0.10[b]	7.51±0.09[a]	0.01**
Urinary outgo (g)	4.65±0.24[b]	5.64±0.29[a]	0.01**
Balance (g)	7.49±0.25[b]	9.70±0.28[a]	0.01**
Balance (%)	39.31±1.34[b]	42.43±1.11[a]	0.01**
Calcium (g/day)			
Intake (g)	5.36±0.02[b]	10.49±0.03[a]	0.01**
Faecal outgo (g)	2.57±0.04[b]	4.68±0.07[a]	0.01**
Urinary outgo (g)	0.14±0.01[b]	0.22±0.02[a]	0.01**
Balance (g)	2.65±0.03[b]	5.59±0.07[a]	0.01**
Balance (%)	49.52±0.61[b]	53.25±0.62[a]	0.01**
Phosphorus (g/day)			
Intake (g)	4.08±0.02[b]	5.30±0.02[a]	0.01**
Faecal outgo (g)	1.73±0.03[b]	2.11±0.02[a]	0.01**
Urinary outgo (g)	0.12±0.00[b]	0.15±0.00[a]	0.01**
Balance (g)	2.23±0.02[b]	3.04±0.03[a]	0.01**
Balance (%)	54.59±0.57[b]	57.38±0.41[a]	0.01**

Means bearing different superscripts in rows differ significantly
**P < 0.01 *P <0.05

Table 14. Rumen fermentation parameters in goats fed super Napier hay and concentrate mixture or gram straw based complete feed pellets

Parameters	Groups		Significance
	Control	Treatment	
pH	6.5±0.0	6.5±0.0	1.000
Total nitrogen (mg/100 ml SRL)	80.73±2.11[b]	91.93±2.11[a]	**
TVFA (mEq/100ml SRL)	10.25±0.26[b]	11.75±0.38[a]	**
Bacterial count x 10^{10}/ml of SRL	1.03±0.02[b]	1.23±0.01[a]	**
Protozoan count x 10^{6}/ml of SRL	1.55±0.06[b]	1.98±0.09[a]	**

Means bearing different superscripts in rows differ significantly. **P < 0.01

Rumen liquor profile: The rumen liquor pH shows non-significant difference between the groups (Table 14). The total nitrogen (mg/100 ml SRL), TVFA (mEq/100 ml SRL), total bacterial count (x 10^{10}/ml of SRL) and protozoan count (x 10^{6}/ml of SRL) in the rumen liquor of goats in the treatment group revealed significantly more concentrations than in the goats of the control group. Rumen motility was not significantly different between groups. Omotoso et al (2021) also reported non-significant difference in the rumen liquor pH of West African dwarf sheep on feeding with mixed rations of crop residues. Nagalakshmi and Reddy (2012), Jadhav (2019), and Shembekar (2019) reported increased concentrations of TVFA and total nitrogen in the rumen liquor on feeding with crop residue-based complete feed either in block or pellets form. Senani et al (2013) also reported a higher total bacterial count in the rumen liquor of Bandur lambs on feeding with ragi straw and maize cobs based complete rations. However, Karimizadeh et al (2017) observed higher protozoan count in the rumen liquor of lambs fed bagasse pit-based complete feed blocks than in the mash and pellets forms.

Hemato-biochemical parameters: The haematological parameters (Table 15) *viz*., Hb (g/dl), PCV (%), TEC (x 10^{6}/µl) and TLC (x 10^{3}/µl) and blood biochemical parameters (Table 16) *viz*., total protein (g/dl), serum creatinine (mg/dl), total cholesterol (mg/dl), SGOT (U/L), SGPT (U/L), serum albumen (g/dl) and serum globulin (g/dl) differ not significantly between the goats of treatment and control group. Blood glucose (mg/dl) concentration was significantly higher in the goats of the treatment group in comparison to the control. Malik et al. (2020) also observed that the amount of straw or the physical form of the male Beetal goats diet had no influence on blood metabolites or blood cell count. Rumen fermentation pattern changes on feeding with pellet diet, which increases propionate production and that is a source for higher glucose production for cellular growth and development (Huyen et al 2012). The high intake of the TMR diet resulted in an increased supply of precursors for hepatic gluconeogenesis and resulted into higher blood glucose

Table 15. Haematological parameters in goats fed super napier hay and concentrate mixture or gram straw based complete feed pellets

Parameter	Start of experiment		P Value	End of experiment		P value
	Control	Treatment		Control	Treatment	
Hb g/dl	8.20±0.15	8.28±0.16	0.538	8.27±0.15	8.33±0.18	0.496
PCV%	22.77±0.70	22.87±0.78	0.745	22.87±0.71	22.98±0.78	0.793
TEC x 10^{6}/µl	8.37±0.25	8.37±0.22	1.000	8.40±0.24	8.38±0.21	0.901
TLC x 10^{3}/µl	7.53±0.87	7.55±0.83	0.912	7.67±0.85	8.27±0.87	0.253

Note: Hb-Haemoglobin, PCV-Packed cell volume, TEC-Total Erythrocyte Count, TLC-Total Leucocyte Count

Table 16. Blood biochemical parameters in goats fed super napier hay and concentrate mixture or gram straw based complete feed pellets

Parameter	Start of experiment		P Value	End of experiment		P value
	Control	Treatment		Control	Treatment	
Blood glucose mg/dl	47.42±1.77	47.23±1.82	0.863	48.43±1.55[b]	52.48±1.62[a]	*
Total protein g/dl	6.57±0.23	6.60±0.23	0.804	6.62±0.21	6.78±0.20	0.197
Serum creatinine mg/dl	0.97±0.03	0.97±0.03	0.801	0.97±0.03	0.97±0.04	0.871
Total cholesterol mg/dl	61.25±5.73	62.12±5.48	0.794	60.86±6.06	61.62±5.54	0.827
SGOT U/L	179.02±12.03	179.38±15.98	0.965	179.03±12.05	178.48±15.93	0.948
SGPT U/L	8.18±0.82	8.27±0.73	0.937	8.30±1.62	8.18±1.72	0.906
Serum albumen g/dl	3.78±0.17	3.80±0.15	0.830	3.76±0.30	3.81±0.06	0.709
Serum globulin g/dl	2.79±0.17	2.81±0.18	0.897	2.86±0.20	2.97±0.16	0.291

SGOT- Serum glutamic-oxaloacetic transaminase, SGPT-Serum glutamic pyruvic transaminase, Means bearing different superscripts in rows differ significantly. **P < 0.01

Table 17. Cost of production of goats fed super napier hay and concentrate mixture or gram straw based-complete feed pellets

Feedstuff	Groups	
	Control	Treatment
Average Super napier hay intake (Kg)	15 Kg in 28 days	----
Average concentrate intake /goat	11 Kg in 28 days	----
Average Gram straw based complete feed pellet intake/goat	---	34 Kg in 28 days
Cost of feedstuffs	Hay=Rs. 6/Kg Concentrate=Rs. 34/Kg	Complete feed pellets =Rs. 18/Kg
Cost of feeding	Hay=Rs. 88.8/- Concentrate= Rs. 378.	Complete feed pellets= Rs. 600
Cost of processing	----	Rs. 1/Kg of complete feed =Rs. 34
Total feeding cost	Rs. 4667	Rs. 634
Average total weight gain/ goat	2.65 Kg	4.68 Kg
Cost of feeding per Kg of weight gain	Rs. 176.2/Kg	Rs. 135.42/Kg

levels. The blood glucose level found in this experiment agrees with Delany et al (2010) in cow.

Cost of goat production: The goats in the control group with conventional ration have a lower cost of production (Rs. 466/animal) than the treatment group. The average total weight gain in four weeks was higher in the treatment group (4.68 Kg/ animal) than in the control group (2.65Kg/animal). Due to better utilization of nutrients and higher weight gain in goats fed gram straw-based complete feed with roughage to concentrate ratio of 60:40, the cost of feeding per Kg of weight gain was lower in the treatment group (Rs.135/Kg) than in the control group (Rs.176/Kg). Lower feed cost per kg body weight gain on feeding crop residue-based complete feed in different animals was also reported by Kirubanath et al (2003), Afzal et al (2009) and Ahmed et al (2021).

CONCLUSION

The gram straw based complete feed pellets had more degradable dry matter and crude protein, whereas the *Cajanus cajan* straw based complete feed pellets has more degradable neutral detergent fibre. Groundnut straw based complete feed pellets had higher IVGP. The gram straw based complete feed pellets with 60%-gram straw showed improved performance of goat and proved to be economical.

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Effect of Partial Substitution of Conventional Protein Source with Duckweed on Digestibility and Nitrogen Retention in Beetal Goat

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***Abstract*:** Duckweed is the common name used to refer to members of the aquatic plant family *Lemnaceae*. A duckweed feeding trial was carried out at Goat Farm of the Department of Livestock Production and Management, Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Ludhiana with 20 male goats fed on four different diets. The objective of the trial was to evaluate duckweed (*Spirodela polyrhiza*), duckweed based TMRs (total mix ration) and use as a protein supplement for ruminants. The hypothesis was that duckweed is a suitable protein source for goats and will serve in a similar fashion to soybean meal. The diets included a control having supplemental protein from soybean meal; 1/3, 2/3 and 100% duckweed supplemental protein. The goats were fed equal amounts of fodder and concentrate ration in 50: 50 R: C **(**roughage: concentrate ratio**)** at 4% of body weight as fed. Duckweed supplementation did not have a significant effect on digestibility of acid detergent fiber, crude protein, nitrogen intake, faecal nitrogen outgo, urinary nitrogen and percent nitrogen retention in male goats. Digestibility of dry matter, organic matter digestibility, neutral detergent fiber, hemi-cellulose digestibility, total carbohydrate digestibility and non-fiber carbohydrates were significantly higher in control group and decreased as the level of duckweed supplementation increased in the total mix ration. Duckweed can be incorporated in ruminant diet without any detrimental effects.

***Keywords*:** Duckweed (*Spirodela polyrhiza*), Goats, Rumen fermentation, Retention

One of the most expensive operational costs in livestock production is feed. Duckweed plants can improve the quality of feed thereby increasing consumption and digestibility as well as the balance of protein and energy feed for goats (Rostini et al 2016). In all diet formulations, soybean meal is the most widely used protein supplement as the protein component acts as a critical nutrient in ruminant rations. This expensive universal ingredient has a high amino acid profile. Duckweed can have similar crude protein levels and essential amino acids required in ruminant rations. Dried duckweed protein content varies from 25.2-36.5% (Rusoff et al 1990). The aim of the present study is to compare the nutritional quality of TMR containing degraded levels of duckweed replacing the total crude protein of soybean as the protein source in goats on digestibility and nitrogen retention.

MATERIAL AND METHODS

The duckweed sample used in the study was obtained from the College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Ludhiana and were sun/ air-dried and then ground in a Wiley mill through a 2 mm screen. The total mixed rations (TMR) were prepared by using various duckweed levels sources i.e. control; 1/3, 2/3 and 100% duckweed replacing the total CP of soybean in 50:50 ratio (roughage: concentrate) (Table 1). All the TMR prepared were iso-nitrogenous having approximately 15% CP.

Conduction of metabolic trial: Twenty male goats (15 kg body weight each) were divided into 4 equal groups and were offered with 4 different TMRs *viz*. TMR1 (control), TMR2 (1/3 duckweed), TMR3 (2/3 duckweed) and TMR4 (100% duckweed) for 120 days. During this period, digestibility coefficients of various nutrients, nitrogen balance were observed.

Housing: The male goats were housed in a concrete shed and were stall fed in groups, at 9:00 am daily and had free access to water twice a day and were allowed in the yard daily for an hour.

Metabolism trial: The 7-day metabolic trial was conducted on all the animals in between the growth trial. During metabolic trial, the animals were kept in specially designed metabolic cages where a metallic pipe led the excreted urine into a narrow mouth plastic container (5 liters capacity) containing 100 ml of 20% H_2SO_4. The faeces were collected manually throughout the day. The collection of faeces and urine were done for 7 days. The combined residue of green

and concentrate mixture, if any, were weighed at 9:00 am prior to the following day's ration.

Chemical Analysis: Samples of feed, faeces and orts were analyzed for proximate constituents (AOAC 2000), cellulose (Crompton and Maynard 1938) and cell wall constituents (Robertson and Van Soest 1981).

Statistical Analysis: The data were analysed using SPSS Version 19. The differences in means were tested by Tukey B.

RESULTS AND DISCUSSION

Chemical composition of total mixed ration (TMR) (DM basis -R: C 50:50): The CP content of all TMRs having different levels of duckweed supplementation varied from 14.87 to 15.27%. All the rations prepared were iso-nitrogenous in nature (Fig. 1). The NDF (neutral detergent fiber) content varied from 49.70 to 51.50% while ADF (acid detergent fiber) varied from 26.50 to 34.0%. The fat content of ration was between 2.01 to 2.55%. The ash content in all TMRs varied from 10.20 to 14.37% and OM (organic matter) content from 85.62 to 89.80%. The concentration of total carbohydrates (TCHO) was 67.95 to 72.91% and non-fiber carbohydrates (NFC) was 17.02 to 23.21% with varying levels of duckweed supplementation (Fig. 1).

The DM (dry matter) intake was similar in all the groups (Table 2). There was significant difference in the dry matter

Table 1. Composition of different total mixed rations containing duckweed in 50:50 (R: C)

Ingredient	Control (TMR1)	1/3 duckweed (TMR2)	2/3 duckweed (TMR3)	100% duckweed (TMR4)
Bajra fodder	50	50	50	50
Maize	17.5	17.5	17.5	17.5
Soybean	14	9.3	4.65	0
Duckweed	0	7.75	15.5	23
Wheat bran	8.5	6.5	4	2
Rice bran	7.37	6.3	5.75	4.75
Mineral mixture	1	1	1	1
Salt	0.5	0.5	0.5	0.5
Urea	0	0.15	0.35	0.5
Bypass fat	1.125	1	0.75	0.75

Table 2. Digestibility parameters (% DM basis)

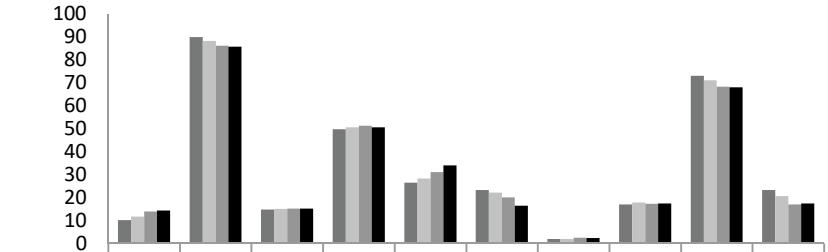
Parameters	Group 1	Group2	Group 3	Group 4	SEM
DM intake (g /d)	458.79	478.54	427.63	458.34	9.48
DMD	65.55^{c}	56.92^{b}	52.26^{a}	52.36^{a}	1.71
NDFD	50.06^{c}	42.84^{b}	40.20^{ab}	37.76^{a}	1.43
ADFD	39.32	35.37	38.83	39.20	0.74
EED	78.23^{b}	74.22^{ab}	75.41^{ab}	72.25^{a}	0.87
Cellulose digestibility	46.51	42.82	42.90	43.86	0.75
HCD	64.52^{d}	52.32^{b}	58.45^{c}	36.83^{a}	3.07
OMD	67.36^{c}	60.12^{b}	54.90^{a}	54.54^{a}	1.60
CPD	80.34	78.12	76.87	77.39	0.59
TCHOD	61.15^{c}	51.43^{b}	44.67^{a}	45.05^{a}	2.08
NFCD	80.90^{c}	78.24^{bc}	74.19^{b}	68.37^{a}	1.54
Nutritive value					
Total TDN digested	274.73^{c}	244.61^{b}	200.90^{a}	214.16^{a}	9.36
TDN%	59.96^{c}	51.10^{b}	46.98^{a}	46.72^{a}	1.66
DCP%	80.34	78.12	76.87	77.39	0.59
DCP (g)	62.47	63.11	58.07	60.49	1.07
Actual CP intake	77.79	80.76	75.54	78.14	1.19

Means bearing different superscripts in a row differ significantly ($P<0.05$)

digestibility (DMD), ADF, NDF, hemicellulose, OMD, total carbohydrate digestibility (TCHOD) and total non-fiber carbohydrate digestibility (NFCD) in control and duckweed supplemented groups. The significant difference in the digestibility (%) of OM was among the four groups and varied from 54.54 in 100% duckweed group to 67.36 in control group. No significant effect on CP digestibility was observed in control and duckweed supplemented group and varied from 76.87 to 80.34% in four groups (Fig. 2).

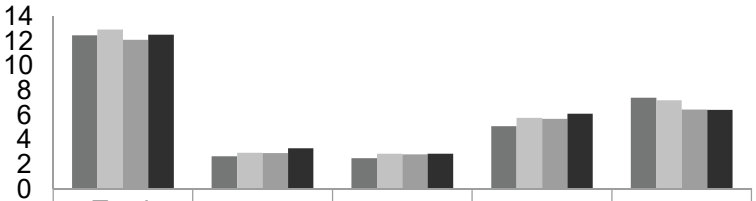
There were no significant differences in the mean values of EE (energy expenditure) digestibility (%) among the groups. The digestibility coefficients EE (%) were 75.44, 68.56, 68.74 and 68.91, respectively in the four groups. The TCHO digestibility (%) differ significantly may be due to different OM, CP, EE intake (g/d), digested (g/d) and digestibility (%) among the four groups. The corresponding values for digestibility (%) were significantly lowest in 2/3 (44.67) and 100% duckweed supplemented groups (45.05) and significantly higher in control group (61.15%) (Figure 2). There was significant difference in digestibility (%) of NDF in all the groups excluding control. The NDF digestibility was lowest in 100% duckweed supplemented group (37.76%) and highest in control group (50.06%). The NFC digestibility was significantly lower in 2/3 duckweed supplemented group (54.19%) and highest was in control (82.57%) and 1/3 duckweed supplemented group (79.57%). The digestibility of cellulose was similar in all the four groups and varied from 42.90 to 46.51%. However, diet type and experimental conditions may influence the results of digestibility studies which may explain the inconsistent findings considered above.

The nutrient requirements of a 20 kg goat at maintenance level to be 267 g TDN (total digestibility nutrient), 22 g CP, 1 g Ca and 0.7 g P (NRC 1981). The average DMI (dry Matter



	Ash	OM	CP	NDF	ADF	HC	EE	Cellulose	TCHO	NFC
TMR 1	10.2	89.8	14.87	49.7	26.5	23.2	2.01	17	72.91	23.21
TMR 2	11.8	88.2	15.07	50.5	28.35	22.15	2.01	17.8	71.11	20.61
TMR 3	13.95	86.05	15.27	51.2	31.1	20.1	2.55	17.3	68.22	17.02
TMR 4	14.37	85.62	15.27	50.5	34	16.5	2.4	17.5	67.95	17.45

Fig. 1. Chemical composition of TMR fed to male goats, % DM basis (R: C 50:50)



	Total nitrogen intake (g/day)	Urinary N (g/day)	Fecal N output (g/day)	Total N outgo (g/day)	N retention (g/day)
Group 1	12.44	2.62	2.45	5.07	7.37
Group2	12.92	2.91	2.82	5.73	7.18
Group 3	12.08	2.87	2.79	5.66	6.42
Group 4	12.5	3.27	2.82	6.09	6.4

Fig. 2. Nitrogen balance

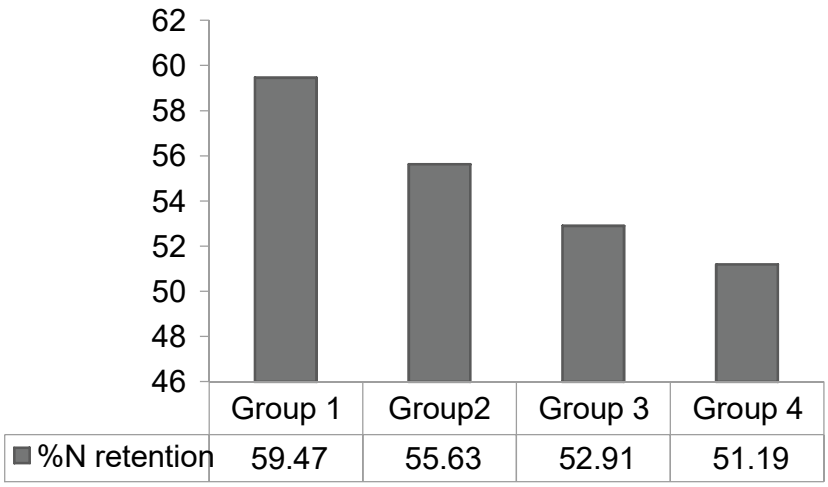


Fig. 3. % N retention

Intake) for the 5 days metabolism trial was 455.34 g/day. There was no significant difference among DMI for the four groups thereby showing that duckweed, when included at 1/3 and 2/3 protein and 100% is palatable as soybean meal. The maintenance requirement of TDN for a 20 kg goat is 267 g. The average weight of the goats fed with the supplemented diets was 16 kg with a TDN of 434 g which fulfilled the maintenance and growing requirement of the animals. All the goats achieved the maintenance requirement of CP which is 38 g for a 20 kg goat. The CP intake of goats on the control was only 77.79 g while the positive control, 1/3 duckweed, 2/3 duckweed and 100% duckweed diets produced intakes of 80.76 g, 75.54 g and 78.14 g respectively. Moore et al 3(2002) and Luginbuhl et al (2000) observed low DMD and fiber digestibility which is in accordance with the present study, i.e., DM and fiber digestibility was lower in duckweed supplemented groups as compared to soybean meal control treatment. Moore et al (2002) reported higher apparent digestibility of DM, NDF, ADF and cellulose for both diets containing hay with soybean meal and soybean hull diet. The higher digestibility reported can be linked to the higher quality hay used in their respective studies.

Nitrogen balance in male goats: The intake of N (g/d) in the groups varied from 12.08 to 12 .92 with non-significant differences. Faecal, urinary and total nitrogen excreted (g/d) were statistically similar among the four groups as no significant effect was seen in control and duckweed supplemented groups. Animals in all the four groups were in positive N balance (Fig. 2). The nitrogen balance studies revealed that nitrogen intake was comparable between all the groups (Fig. 2). The daily total excretion of nitrogen was maximum in 100% duckweed supplemented group followed by 1/3 duckweed, 2/3 duckweed and control groups. The N out go (g/day) was 5.07, 5.73, 5.66 and 6.09 in all four groups. The urinary nitrogen (UN) excretion was highest in goats feed 100% duckweed supplemented group and lowest in control groups. This trend of UN resulted in lowest retention of nitrogen in animals fed with 2/3 and 100% duckweed supplemented diet. The nitrogen retention was highest in control group than that in the other groups, though the results were non-significant (Fig. 2). There was no significant difference in the amount of fecal N, UN and N retention (% and g/day) in soybean supplemented control group and varying levels of duckweed supplemented groups in this study (Fig. 3). Maye et al (2002) observed lower N retention than in current study which suggests that duckweed is comparable to soybean hulls as a protein supplement for growth of goats. Although the N digested and the N retained was numerically lower for the duckweed supplemented groups as compared to control, the N retained as a percent of digested was higher in control group was due to the decreased UN output.

CONCLUSIONS

Duckweed supplementation did not have a significant effect on digestibility of ADF, CP, nitrogen intake, faecal nitrogen outgo, UN and %N retention in male goats. DMD, OMD, NDFD, HCD, TCHOD and NFCD was significantly higher in control group which decreased with the increase of duckweed supplementation in the ration. Therefore, duckweed can be incorporated in ruminant diet without any detrimental effects.

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Energy Input and Output Use Pattern in Wheat Crop Production System in South Western Zones of Punjab, India

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Abstract: The present study was carried out to assess and examine the input and output energy use pattern for the cultivation of wheat crops in the Muktsar district of Punjab, India. The local farmers were interviewed and information was collected for various inputs used in the wheat crop production system during the survey in the village. Based on the information received from local farmers, the various inputs used for raising wheat crops were identified and converted into energy with the help of standard energy equivalents. The results showed that the total energy expenditure was 28244.126 MJ/ha in the region for wheat crop production. The largest share was shared by diesel energy input of approximately 39 %. The total input energy in fertiliser and electricity was 32 % and 19 %. The total direct and indirect energy used for wheat cultivation was 19.57 and 14.39 %, respectively. The overall renewable energy used was 3 % and the rate of use of non-renewable input energy was 30.96 %.

Keywords: Wheat, Input energy use, Output energy, Energy ratio, Energy use pattern, Wheat crop, Specific energy

India is the second largest wheat producer in the world and the 10th largest wheat exporter in the world. In 2020, global wheat production reached 761 million tons, led by China, India, and Russia combined 38% of the total world. India's wheat production increased from 36 million tons in 1980 to 107 million tons in 2022. North India traditionally dominates wheat cultivation in India. The demand for Indian wheat in the world showed an upward trend. The country exported 7,239,366.80 metric tons of wheat to the world worth Rs 15,840.31 crores in the year 2021-22. Punjab contributes 15-20 % (Around 17.57 million tonnes) of total wheat production in India with an average growing rate of 2.36 per year (Anonymous 2022). Agriculture can be characterised as both a producer and an energy consumer. They use large amounts of locally available commercial and non-commercial energy including seeds, manure, and animal energy, as well as direct and indirect energy in the form of irrigation water, electricity, fertilizers, machinery, diesel, etc (Khalaj et al 2023). The efficient use of this energy contributes to increased production and productivity which contributes to the profitability and competitiveness of rural agriculture. The increase in energy use has brought with it several important problems for human health and the environment, therefore, the efficient use of inputs has become more important for sustainable agricultural production.

Energy plays an influential role in the development of important sectors of economic importance, such as agriculture, industry, and transportation. Many researchers are focusing their research on the energy management of various types of agricultural practices. Energy consumption for almost all agricultural activities in developing countries has increased very rapidly as a result of current economic growth and development (Saber et al 2020). Energy inputs and outputs are both very important factors in determining energy efficiency and its environmental impact on crop production systems. Energy use and production vary between crops, production systems, and the intensity of various management practices. However, the increased use of inputs in agricultural production may not maximize profits due to higher production costs. Energy, the economy, and the environment are interrelated. The profitability and productivity of the agriculture production system depend on energy consumption (Kashyap and Agarwal 2021). The amount of energy used depends on the level of mechanization, the amount of active agricultural work, and arable land. Hence, the main purpose of this study was to determine the energy flow pattern in the wheat cultivation process in the Muktsar region of Punjab, India.

MATERIAL AND METHODS

Study location description: Muktsar district lies in the south-western part of the state and lies between North Latitude 30°28'04.6" and East Longitude 74°29'17.9" which falls in the Ferozepur division. The climate of the region is dry and semi-humid and receives an average annual rainfall of

430.7 mm on 22 rainy days. The monsoon period contributes 79 % of annual rainfall and the remaining 21% occurs during the non-monsoon period. The main sources of irrigation in the region are canals and tube wells. The wheat crop is sown between late October to December, while it's harvesting usually starts in April.

Methodology: The preliminary data was collected related to the different input sources used for wheat cultivation in the region from the farmers. The preliminary information included input sources such as various machinery systems used for cultivation from tillage activities to the harvest process. The energy consumption in production agriculture to grow a particular crop varies due to its climatic agricultural location, crop production, and management practices, agriculture machinery availability, mechanization status of the region, consumption pattern of different types of energy inputs in different forms, and other inputs used in raising the corresponding crops. Therefore, queries were made from the group of farmers related to sources of irrigation, and amount of water used, and types of fertilizer used by farmers. The number of human power and quantity of seeds, diesel, electricity, farm yard manure, chemicals, and fertilizers used per hectare were also considered for a better understanding of the cultivation practice. To determine the input and output energy for the overall cultivation process, the physical quantities of inputs and outputs were multiplied by their corresponding energy conversion equivalents to get the total energy used in megajoules per hectare. Energy production comes mainly from the products and by-products of crops. Some operations like transportation and disposal/removal of agricultural residues were not included in the evaluation. Therefore, the total estimated energy consumption applies to the crop production system before the post-harvest process. The study evaluated the energy inputs for wheat crops used only in the production process of wheat crops for one growing season and sources without considering the other natural resources such as annual rainfall, solar radiation, and wind. and the energy used for different operations from various sources was calculated by using the energy equivalent (Table 1). The use of human energy was assessed based on

Table 1. Energy equivalents for different inputs and outputs in wheat cultivation practice

Parameters	Unit	Energy equivalent	Source
Input parameters			
Human labour	h	1.96 MJ/h	Kumar et al 2018
Machinery	h	62.7 MJ/h	Kumar et al 2018
Combine	h	68.4 MJ/h	Sharma et al 2020
Tractor	h	68.4 MJ/h	Sharma et al 2020
Trolley	h	62.7 MJ/h	Sharma et al 2020
Disc harrow	h	62.7 MJ/h	Sharma et al 2020
Cultivator	h	62.7 MJ/h	Sharma et al 2020
Planker	h	62.7 MJ/h	Sharma et al 2020
Bund former	h	62.7 MJ/h	Sharma et al 2020
Straw Reaper	h	68.7 MJ/h	Sharma et al 2020
Reaper	h	62.7 MJ/h	Sharma et al 2020
Submersible pump (15 hp)	h	68.4 MJ/h	Sharma et al 2020
Knapsack sprayer	h	62.7 MJ/h	Sharma et al 2020
Electricity	kW/h	11.93 MJ/h	Kuswardhani et al 2013
Diesel	L	56.31 MJ/lit	Kumar et al 2018
Chemical fertilizers			
Topic	kg	120 MJ/kg	Kuswardhani et al 2013
Algrip	L	120 MJ/lit	Kuswardhani et al 2013
Tilt	L	120 MJ/lit	Kuswardhani et al 2013
Rogar	L	120 MJ/lit	Kuswardhani et al 2013
Fertilizers spraying			
Nitrogen	kg	60.60 MJ/kg	Shrivastava et al 2022
Phosphate	kg	11.1 MJ/kg	Mousavi-Avval et al 2011
Potash	kg	6.7 MJ/kg	Ziaei et al 2013
FYM	kg	0.30MJ/kg	Jin et al 2018
Wheat seed	kg	14.7MJ/kg	Ziaei et al 2013
Output parameters			
Wheat grain yield	kg	14.7MJ/kg	Shrivastava et al 2022
Wheat straw yield	kg	12.50MJ/kg	Shrivastava et al 2022

the time consumption of labour activity and the total number of people involved in each operational process. A labours' total energy spent was assessed by the multiple of the total number of hours of labour activity in a given unit process with the energy coefficient of labour for an hour worked per unit per operation including manual and mechanicals. The main input for fuel in wheat production was high-speed diesel used in agricultural machinery such as tractors, combine, reaper, and submersible pump sets. To calculate the reliable data on the fuel consumption by different operations with the help of the following relationship (Singh et al 2020).

$$F = (LCF \times RHP \times SFC) / 1000$$

Where "F" is the fuel consumption of fuel per unit of time (l/h), "LCF" is the load coefficient factor which is the ratio of actual load on the tractor system to maximum load for corresponding operation whereas "RHP" and "SFC" are rated horsepower in kilowatt (kW) and specific fuel consumption in milliliter per kilowatt (ml/kWh), respectively. The specific fuel consumption and rated horsepower of various agricultural machinery used for each corresponding operation used by farmers for a particular region were taken into consideration from the engine specification of the particular machinery used in the region. The Load coefficient factors used for the study are shown in Table 2. The electricity was mainly used for pumping and irrigation. Electric motors of different ratings were found to be used by different categories of farmers for irrigation purposes. The electricity consumption by electric motor was estimated by the following relationship. Electricity was used in electric motors for irrigation purposes. Electric motors of different classifications appeared to be used by different categories of farmers for irrigation purposes. The electricity consumption was estimated by the following relation.

$$E = RHP \times T$$

where "E" is the electricity expenditure in kilowatts per hour (kWh), "RHP" is the rated horsepower of the electric motor in Kilowatt (kW), and "T" is the total time used for irrigation (h). The energy consumption of the agricultural types of machinery such as tractors, combines and straw reaper for the wheat production system was determined based on the weight of particular machinery, service lifespan, and average working hours for one year. The energy input of the machinery system by using the following formula

$$ME = (G \times E)/ TC_{ef}$$

where "ME" is the machine energy in megajoules per hectare (MJ/ha), and "G "is the total weight of the corresponding machinery system in kilograms (kg). "E" is the total energy consumed by agricultural equipment in megajoules per kilogram (MJ/kg) whereas "T" is the total service lifespan of the machine in hours (h) and "C_{ef}" is the actual field capacity of the agricultural machinery used in the wheat production system in hectare per. (ha/h). After the estimation of total energy input and output, the energy efficiency, specific energy, water productivity, energy productivity, energy intensity, and net energy were determined by using the different relations (Kumar et al 2017) as shown below:

i. Specific energy = Total energy input (MJ/ha) – Grain yield (kg/ha).
ii. Energy efficiency = Total energy output (MJ/ha) – Total energy input (MJ/ha).
iii. Energy productivity = Grain yield (kg/ha) – Total energy input (MJ/ha).
iv. Energy intensity = Total energy input (MJ/ha) – Total energy output (MJ/ha).
v. Energy productivity = Grain yield (kg/ha) – Amount of water applied (MJ/ha).

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

RESULTS AND DISCUSSION

The total input and output energy for the cultivation of wheat crops was 28244.126 and 115795 MJ/ha. The total of human energy in all operations including tillage, sowing, bund making, irrigation, fertilizer and chemical spraying, and harvesting was found to be 201.39 MJ/ha. The total of different types of machinery inputs during form operations was found to be 602.986. The total energy consumed by electricity was 5368 MJ/ha. The largest share was contributed by diesel energy around 11136.99 MJ/ha. The total input energy for chemicals and fertilizers used in the study was 227.76 and 1617 MJ/ha whereas the total input energy for wheat seeds was 9090 MJ/ (Table 3). The specific

Table 2. Load coefficient factor (LCF) for different unit operations from various power sources

Power source	Type of work	LCF
Stationary diesel engine	Threshing	0.8
	Water-lifting	0.6
Tractor	Heavy work such as primary tillage	0.6
	Medium work such as secondary tillage, sowing intercultural operations, etc.	0.5
	Light work such as transport, water-lifting, etc.	0.4

Table 3. Input and output energy use pattern per unit hectare in wheat production

Parameters	Energy equivalent (MJ/unit)	Energy consumed (MJ/unit)	Total energy consumed (MJ/ha)	Total share (%)
Input parameters				
Human labour (Includes all operations)	1.96 MJ/h	102.75 man/ha	201.39	0.71
Machinery				
Combine	68.4 MJ/h	1.5	42.68	2.14
Tractor	68.4 MJ/h	25	342	
Trolley	62.7 MJ/h	6.25	78.375	
Disc harrow	62.7 MJ/h	5	36.366	
Cultivator	62.7 MJ/h	3	9.405	
Planker	62.7 MJ/h	3.5	16.458	
Bund former	62.7 MJ/h	1	2.069	
Straw Reaper	68.7 MJ/h	2.5	41.22	
Reaper	62.7 MJ/h	1	3.135	
Submersible pump (15 hp)	68.4 MJ/h	40	27.36	
Knapsack sprayer	62.7 MJ/h	25	3.918	
Electricity	11.93 MJ/h	450	5368 MJ/ha	19.01
Diesel	56.31 MJ/lit	197.78	11136.99	39.43
Chemical fertilizers				
Topic	120 MJ/kg	0.5 kg/ha	60	0.81
Algrip	120 MJ/lit	0.025 lit/ha	3	
Tilt	120 MJ/lit	1 lit/ha	120	
Rogar	120 MJ/lit	0.373 lit/ha	44.76	
Fertilizers spraying				
Nitrogen	60.60 MJ/kg	120 kg	7272	32.18
Phosphate	11.1 MJ/kg	60 kg	666	
Potash	6.7 MJ/kg	60 kg	402	
FYM	0.30MJ/kg	2500 kg	750	
Wheat seed	14.7MJ/kg	110 kg	1617	5.72
Total input energy (MJ/ha)			28244.126	
Output parameters				
Wheat grain yield	14.7MJ/kg	4850 kg	71295	61.57
Wheat straw yield	12.50MJ/kg	3560 kg	44,500	38.42
Total output energy (MJ/ha)			115795	

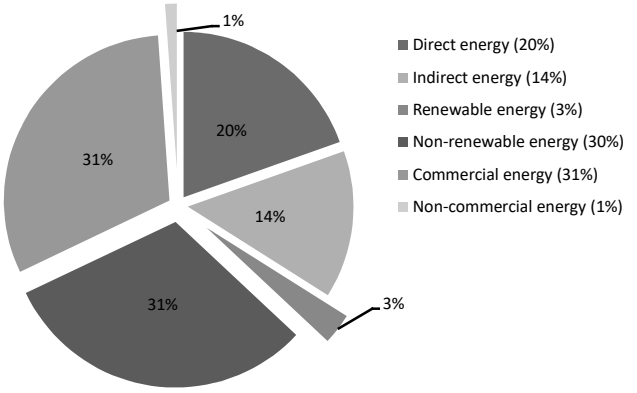

Fig. 1. Energy input (MJ/ha) in different modes of energy source in wheat crop

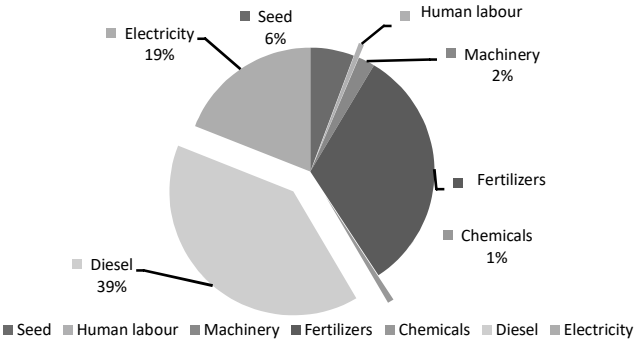

Fig. 2. Energy input (MJ/ha) share percentage from different energy sources in wheat crop

energy and energy efficiency were 0.4 and 4.1 MJ/ha, respectively. The energy productivity and energy intensity were 2.52 kg/MJ and 0.24, respectively. And the net energy was 87550.87 MJ/ha. Direct and indirect energy was found to be accounting 20 and 14% of energy inputs. The largest share was contributed by commercial and non-renewable energy whereas a very less percentage of non-commercial and renewable energy (Table 4; Fig. 1). The energy input (MJ/ha) share percentage from the different energy sources in wheat crops is shown in Figure 2.

CONCLUSION

Energy use efficiency in wheat crop production systems varies from region to region depending upon many factors. The total input energy consumption for raising wheat crops was 28244.126 MJ/ha. The largest share was consumed by diesel, fertiliser and electricity. Therefore, need to focus more on fuel consumption, fertilizers, and electricity to reduce energy consumption in growing crops compared to other factors. More improved wheat crop management practices and procedures must be followed to increase the efficiency of nitrogen use. It is also necessary to educate the farmers about a zero-tillage system and other energy-saving agricultural machinery that can save a large amount of energy to reduce farm energy consumption and improve energy efficiency.

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Environmental Accounting of Educational Institutes during Pre-COVID-19 and COVID-19 in Kangra district of Himachal Pradesh, India

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Abstract: Environmental accounting is one of the most effective methods for assessing environmental management and sustainability. Educational institutes provide a clear image of the footprint of such micro-level organizations. To estimate the environmental accounting, it becomes necessary to assess the biocapacity and ecological footprint. In this paper, the kinds of resources used are listed and estimated with the formula and component-based approach to assessing the sustainability of educational institutes. This research employs a novel approach to communicate the concept of sustainability, demonstrating the influence of communal behaviors on the natural environment. The descriptive method was used to analyze the ecological footprint of six selected educational institutes of the Palampur region of Kangra district (HP) during 2019-2020 (pre-COVID-19) and 2020-2021 (COVID-19 period). With the help of suitable formulae, assessment of components like energy, water, food, solid waste, material, biocapacity is done. Results indicated that the average ecological footprint in all the selected educational institutes during pre-COVID-19 and during COVID-19 was found to be 0.3380 gha and 0.1356 g ha respectively. During pre-COVID-19 and during COVID-19 campuses were found to be sustainable. Further, there's a need to reduce the environmental footprint to the maintenance of the sustainability of the institutes.

Keywords: Ecological footprint, Biocapacity, Ecological deficit or reserve, Sustainability

Humans play a crucial role in the world's ecology. In India with a population of 1.36 billion and still counting, we are gradually depleting our natural resources very quickly without thinking about the next generation's survival. Our natural resources becoming obsolete like groundwater and issues with the food security of the country challenges us, environmental accounting become essential to check our needs and greed. It acts as a management tool that measures the area in global hectares per capita (GHA). A global hectare is equivalent to one hectare of land with global average productivity (Kitzes et al 2007). The ecological footprint calculates the amount of area required to generate and absorb the resources that a population consumes its wastes (Sudarsan et al 2019). It is also a method for communicating the principle of sustainability in educational institutes (Gottlieb et al 2012). The general concept of ecological footprint study is that all energy and material consumption, as well as all waste discharge, need a finite amount of land and water area for resource production and waste absorption over a certain length of time. A study in Iran shows that Sitan and Baluchestan province having high ecological footprint. With increase in urbanization, demand for natural resources enhances and framed policies to implemented to optimize the industrial structure, economic transformation, and ecological restoration of resources, to achieve sustainable use of natural capital and economic growth (Mir et al 2022). Japan's ecological footprint which mainly focused on sustainability management for calculating the subnational ecological footprint used a methodology, which was developed by a global footprint network. It was done in three steps; 1) calculation for national level carbon footprint for production; 2) maintaining multi-regional input-output relation and 3) scaling down EF to prefecture level with household level. The total Ecological Footprint per capita was highest in Tokyo i.e., 5.24 g ha. (Tsuchiya et al 2021). Ecological accounting done in Czech Republic and they conducted a survey and found that humanity's ecological footprint (20.6 billion g ha) was greater than bio-capacity (12.2 billion g ha), indicating that human consumption has outpaced the planet's regenerative and assimilative ability. This means that there is a worldwide environmental.

MATERIAL AND METHODS

The environmental accounting of selected six educational institutes of Palampur region in Kangra district was taken to examine their absorption pattern in the campus during the period of 2019-2020 (before COVID-19). The components considered for examining the ecological footprint were

energy, water, food, solid waste, and material (paper usage). The necessary data required to calculate the EF values were collected with the help of a survey. The institute's administration staff provided data on annual electric power, water, material consumption, and office paper use. A survey was carried out among students and staff to estimate paper consumption, water use, food and material and waste generated

Energy analysis: The energy used in selected educational institutes was estimated by the formula given by Gottlieb et al (2012).

E= 1/KJ × 1G÷ 20 Kj

One plant has a coal yield of 31.4%. Coal required to generate electricity EC = E÷ 0.314

Since 85% of coal is carbon. Therefore, plant coal yield (Ey in ton)

Ey = Ec × 0.85÷100000

1 ha of land can absorb 1.8 ton of carbon

EF (power) = Ey÷1.8 = EF (g ha)

Water footprint: Water footprint was estimated by the formula given by Habibi et al (2015)

Water footprint (gha m^{-3} yr^{-1}) = Total consumption (gha m^{-3} yr^{-1}) × land area (ha) × 1000000

Food footprint: This methodology was given by Habibi et al (2015)

Food requirement (ton) = (total population of the institutes × total consumption per capita) 1000 kg

Land (ha) required for the production of 1 ton crop = arable land total agriculture crops grown

Ecological footprint of food (g ha) = food requirement × land for the production of 1 ton crops

The data on arable lands and their crops in the agricultural year 2019-2020 was obtained from District Agriculture Plan, Kangra, Himachal Pradesh Volume-IV to calculate land used to produce one ton of crops.

Material footprint: The formula for material analysis was given by Gottlieb et al. (2012)

Material footprint (gha $year^{-1}$) = items $year^{-1}$ (kg) × EF per item (g ha kg^{-1})

Biocapacity is productive hectares of an area

Solid waste footprint: The formula to estimate solid waste EF was given by Habibi et al (2015)

Solid waste EF (gha) = (SW × 8×10000) ÷ 450

where SW = Solid waste generated (kg)

Ecological deficit or reserve: The formula to determine ecological deficit or reserve was given by Monfreda et al (2004)

Ecological deficit or reserve (g ha) = biocapcity (g ha) – ecological footprint (g ha)

Per capita ecological footprint

EF per capita (g ha) = Ecological footprint (EF) Total population of the institutes

Due to the high rate of consumption and modern infrastructure that adversely affect the sustainability of that area, the average ecological footprint was maximum in St. Paul's school of Kangra district of Himachal Pradesh (Table 1). Energy EF was maximum in A.B.M. school (7.277 g ha) as compared to other institutes and least was in Dr. G.C. Negi College. Water EF was maximum in KLB DAV (Girl) College (0.05000 g ha) and minimum was in A.B.M school (0.00010 g ha). Food EF was maximum in SCVB Govt. Degree College (359.0000 g ha) and least was in GSSS (Girl's) (2.0365 g ha). Packaged food consumption, especially dairy products lead to an increase in the ecological footprint of that area. Japan's ecological footprint was assessed, and policy was formulated to check food consumption. (Tsuchiya et al 2021). Material EF was most in SCVB Govt. Degree College (440.22gha) and least in GSSS (Girl's) (100.00 g ha). Solid waste EF was most in Dr. G.C. Negi College (7.0440 g ha) and least was in A.B.M school (0.0025 g ha). The SCVB Govt. Degree College and Dr. G.C. Negi College were close enough in their average ecological footprint. The least ecological footprint was found to be in GSSS (girls). The lifestyle is followed and components management is done ethically and proper regulations are invested to treat their wastage which gradually decreases the ecological footprint. The ecological footprint of five components in selected educational institutes during COVID-19 is presented in Table 2.

Due to the complete and partial lockdown during the various months of the academic year 2020-2021, the

Table 1. Educational institute-wise ecological footprint (g ha) during pre-COVID-19

Educational institutes	Energy EF	Water EF	Food EF	Material EF	Solid waste EF
GSSS (Girls)	1.754	0.00025	2.0365	100.00	0.0032
A.B.M School	7.277	0.00010	120.0000	260.40	0.0025
St. Paul's School	1.461	0.00050	150.0000	440.20	0.0128
SCVB Govt. Degree College	1.266	0.00080	359.0000	440.22	0.0512
Dr. G.C. Negi College	1.041	0.01200	110.2690	296.06	7.0440
KLB DAV (Girls) College	4.590	0.05000	167.2500	140.00	1.0200

consumption rate of various components on the campus decreased which ultimately lower the ecological footprint as compared to other academic years. As compared to other educational institutes the energy EF was maximum in KLB DAV (Girl's) College (0.0020 g ha) and GSSS (Girl's), A.B.M school and St. Paul's School with EF 0.0001gha. Sudarsan et al (2019) also found results along the same lines, per capita EF (0.00500 g ha) of energy in educational institutes of South India. Water EF was maximum in Dr. G.C. Negi College (0.011000 g ha) and least in GSSS (girls) 0.000004 g ha. Food EF was maximum in Dr. G.C. Negi College (1.0270 g ha) and least in A.B.M school (0.0100 g ha). KLB DAV (Girl's) College with maximum EF 2.89000 g ha and least in GSSS (Girl's) (0.00211 g ha). Solid waste EF maximum in St. Paul's School (0.21400 g ha) and least in KLB DAV (Girl's) College (0.00010 g ha).

The average ecological footprint during pre-COVID-19 was higher than during COVID-19 (Table 3). Due to lesser usage of material (paper), packaged food items, electricity usage, and water consumption during COVID-19, decreased the EF. Shifting to online mode leads to lesser usage of paper. Food manufacturing in canteens and mid-day meal food (in Govt. institutions) leads to a decreased food EF. Water requirements and solid waste generation ultimately decreased.

The average ecological footprint per capita during pre-COVID-19 and during COVID-19 was 0.33805gha and 0.135600 gha respectively (Table 4). Components like food and material have high EF per capita during pre-COVID-19 as compared to other components. The results are found same as in Habibi et al. (2015). Water and energy contribute the least to EF per capita. During the COVID-19 period, material and solid waste have high EF per capita, and energy and water contribute the least.

Ecological deficit or reserve (gha) and biocapacity (gha) during the pre-COVID-19 period: To calculate the ecological deficit or reserve, biocapacity (BC) in hectares was converted into global hectares as prescribed by Lin et al (2018). The difference between biocapacity per capita (gha) and ecological footprint per capita (gha) is ecological deficit if -ve or reserve if +ve. The average EF per capita was found to be 0.33805 g ha. The highest biocapacity per capita was 2.9gha in the case of Dr. G.C. Negi College followed by GSSS (Girl's) (2.55 g ha) and lowest (0.131 g ha) was in SCVB Govt. Degree College. The per capita EF in each institute was lesser than the biocapacity of the respective institute which shows that every institute has an ecological reserve. The highest ecological reserve (2.692 g ha) was in Dr. G.C. Negi College followed by Dr. G.C. Negi College and the least (0.084 g ha) was in SCVB Govt. Degree College (Fig. 1).

Ecological deficit or reserve (gha) and biocapacity (gha) during the COVID-19 period: During COVID-19, the average EF per capita was 0.135600 g ha, which was quite lower than during the pre-COVID-19 period. EF per capita

Table 3. Educational institutes wise average ecological footprint (g ha) during pre and COVID-19

Educational institutes	Pre- COVID-19	COVID-19
GSSS (Girls)	20.757	0.001
A.B.M School	77.535	0.027
St. Paul's School	118.334	0.247
SCVB Govt. Degree College	88.390	0.257
Dr. G.C. Negi College	82.885	0.407
KLB DAV (Girl's) College	62.580	0.603

Table 4. Component-wise per capita ecological footprint (g ha) during the pre-COVID-19 and COVID-19 period

Components	Per capita EF	
	Pre-COVID-19	COVID-19
Energy	0.15110	0.000037
Water	0.00009	0.002733
Food	0.81280	0.021400
Material	0.56000	0.451300
Solid waste	0.16630	0.202700
Average EF	0.33805	0.135600

Table 2. Educational institutes wise ecological footprint (g ha) during pre-COVID-19

Educational institutes	Energy EF	Water EF	Food EF	Material EF	Solid waste EF
GSSS (Girls)	0.0001	0.000004	0.0511	0.00211	0.00103
A.B.M school	0.0001	0.006400	0.0100	2.00500	0.00011
St. Paul's School	0.0001	0.000200	1.0200	0.00200	0.21400
SCVB Govt. Degree College	0.0002	0.000500	0.0220	1.25000	0.01250
Dr. G.C. Negi College	0.0010	0.011000	1.0270	1.25000	0.00700
KLB DAV (Girls) College	0.0020	0.000400	0.1270	2.89000	0.00010

was very much lower than that of biocapacity which gives a positive sign of a sustainable environment. Consumption patterns during COVID-19 should be followed to retain a balanced environment. The educational institute with a maximum (2.9 g ha) BC per capita was Dr. G.C. Negi College and the minimum (0.131 g ha) BC per capita was in SCVB Govt. Degree College (Fig. 2). The EF per capita ranged from 0.0015 to 0.0646 g ha. The maximum (0.0646gha) EF per capita was in SCVB Govt. Degree College and the minimum in GSSS (Girl's) (0.0015 g ha).

Sustainability of educational institutes: Agenda 21 of UNCED, 1992 was adopted to act globally, nationally and locally in areas where the environment can be affected by humans. To meet SDGs 12, 15 and 16 the present study was conducted. To assess the sustainability of educational institutes a questionnaire-based survey was conducted among the students and school staff (teaching and non-teaching staff). The selected institutes were less sustainable during the pre-COVID-19 period and more sustainable during COVID-19. During pre-COVID-19, the more frequent use of private vehicles and paper usage was high in offices and by students leading to high usage and more ecological footprints. The packed food and dairy products consumption were quite high, more food was prepared in canteens and mid-day meals with improper disposal of waste resulting in more footprints. During COVID-19, due to the complete and partial lockdown during the year 2020-2021, office work was conducted through online mode, decreased paper usage, and private vehicle movement was restricted, lowering the ecological footprint of the campuses and making it more sustainable. Now knowing these scenarios there's a need to make students more aware of healthy consumption habits to further reduce or maintain sustainability. In the current scenario, the concept of EF was incorporated in the high schools and made them familiar with the footprint calculators to calculate their own footprint on daily basis to change their attitude towards resources and make daily smart decisions to live sustainably. This requires students to think critically and have systematic thinking skills to unfold the complexity and implications of sustainability.

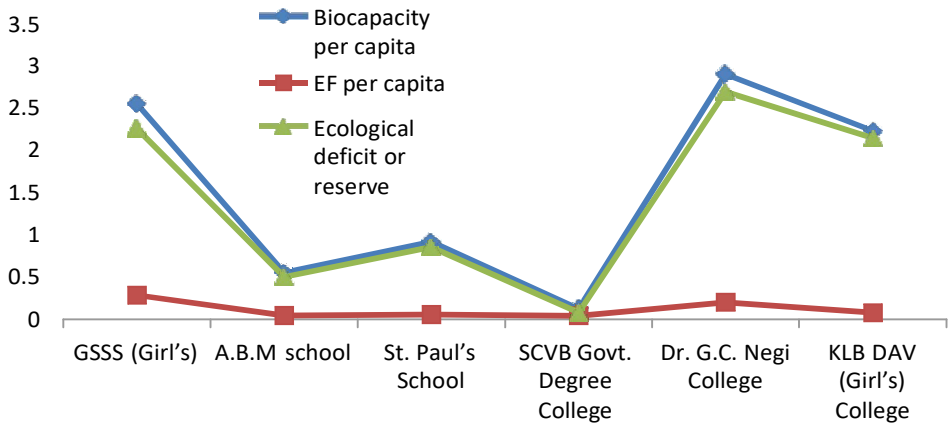

Fig 1. Variation in ecological deficit or reserve and biocapacity during the pre-COVID- 19 period (g ha)

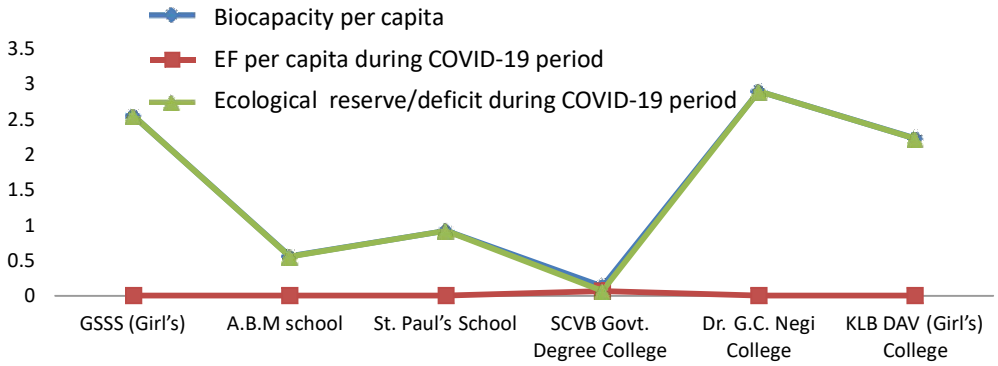

Fig. 2. Variation in ecological deficit or reserve (g ha) and biocapacity (g ha) during the COVID-19 period

CONCLUSION

The main motive behind the environmental accounting of educational institutes is to assess the current usage of natural resources and the sustainability of the institutes. The average ecological footprint per capita during pre-COVID-19 was higher than during COVID-19. The EF and food EF were the major contributors to the ecological footprint. The biocapacity per capita was 0.258 ha. The biocapacity per capita was higher than the EF per capita during the pre-COVID-19 and during the COVID-19 period. The selected educational institutes were in ecological reserves during the pre-COVID-19 and COVID-19 periods. Keeping in view of consumption of natural resources presently, the institutes are likely to become unsustainable. The awareness regarding the use of electric vehicles or pooling the vehicle for transportation and reducing waste & its management should be made to reduce the ecological footprint to meet SDGs 12, 15, and 16.

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Perception of Farmers and Challenges during COVID-19 Pandemic in Haryana, India

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***Abstract*:** The study was conducted in Rohtak District of Haryana State to study factors affecting perception of farmers and challenges faced by them. The majority of the farmers were agreeing to the statement that there is low availability of labour followed by impact wages of labour, main selling channel for produce, changed prices of the agricultural output and changes in price of agri. inputs. About 48.30 percent of farmers had medium level of perception regarding covid-19. Half of the farmers who belonged to 36-50 years age category had medium level of perception regarding covid-19, majority of the farmers were marginal farmers and had low level of perception regarding covid-19. 25.00% farmers had income between 3 to 6 lakhs. Education and mass media exposure were found significantly associated with perception level regarding covid-19 at χ^2=9.5 and χ^2=12.**3** while age, caste, family type, family size, size of land holding, annual income, subsidiary occupation, and extension contacts were non-significantly associated with perception level of the respondents.

Keywords: Covid-19, Farmers, Perception level, Socio-economic factors

Covid-19 epidemic was a significant event that had a global impact on billions of people. Coronavirus had a catastrophic impact on every facet of life globally and the Indian agriculture was no exception. The pandemic highlighted the struggles encountered by farmers, particularly in nations with an agrarian economy. These nations were combating the high rates of poverty, hunger, debt, and farm bankruptcies, but the epidemic further aggravated the prevalent issues and made the matters worse (Menon and Vogt 2022). For the agrarian Indian economy, the agricultural and allied sector is of utmost importance, contributing one-sixth of the national income approximately (NABARD 2020) and employing 263 million workers comprising of 55% as agricultural labour and 45% as cultivators (Menon and Vogt 2022). Covid-19 had an impact on agriculture's supply and demand (Nabard 2020) as well as disrupted the world's supply chain due to tightened sanitary controls, transit restrictions, a lack of raw material supplies, and closures of the food distribution and processing industries(Ebel et al 2022). The unexpected enactment of the lockdown in India had an impact on agriculture sector, resulting in unharvested crops, labour shortages, delays in planting the subsequent crops, inadequate supply of agricultural inputs, along with poor access to services, credit, and advisory facilities (Habanyati et al 2022). Farmers were in a state of vexation due to the constant inconveniences faced in marketing and delivery of their crops to the Agricultural Produce Marketing Committees (APMC) mandis (Behura and Dash 2020, Menon and Vogt 2022). Farmers engaged in horticultural activity especially fruit and vegetable growers were compelled to sell their perishable produce at incredibly low rates due to a lack of storage amenities, items restricted market access and inadequate post-harvest treatment (Behura and Dash 2020, Habanyati et al 2022). The dearth of labour had an effect on farming operations, from planting to processing crops after harvest, which had an impact on crop management, production, and post-harvest handling and resulted in crop losses.

The pandemic and its economic reverberations burdened the agricultural sector in the country therefore, it became necessary to prioritize the agriculture industry and ensure a speedy socio-economic recovery for the nation while upholding the sustainability ethos (NABARD 2020). In view of this, the present study was designed to know the nature and extent of perception of farmers regarding Covid-19, assess the level of perception of farmers and delineate the socio-economic factors associated with perception level of the farmers.

MATERIAL AND METHODS

The study was conducted in Rohtak District of Haryana State. Three blocks were selected from Rohtak district village Titoli and Sunderpur from block Lakhan Majra; Samar Gopalpur from Samar Gopalpur Kalan block; Bhagwatipur and Bahu Akbarpur from Rohtak block were selected. One hundred and twenty farmers were surveyed with the help of well-structured interview schedule. The data was collected by interview method from the respondents to gather

information on dependent and independent variables. The data were coded, tabulated, analyzed, and interpreted according to the objectives of the present study with the help of appropriate statistical techniques. The descriptive statistical tools such as frequency, percent, chi-square, weighted mean, and total weighted score were calculated to draw the inference. The data was tabulated, classified, and analyzed by application of suitable statistical tools to work out association of the dependent and independent variables so as to draw meaningful inferences of the study.

RESULTS AND DISCUSSION

Perception of the farmer families: The 83.30% of the farmers were agreeing to the statement that there is low availability of labour followed by wages of labour, main selling channel for produce, changed prices of the agricultural output s and changes in price of agriculture inputs by (69.30%). The 71.70% of the farmers were not agreeing to the statement that there are job cuts in agricultural sector whereas, only 33.33% of the farmers were agreeing to the statement delay in sowing and harvesting of crops. The results are in line with the impact assessment done by NABARD wherein, there is a decline in availability of agri-inputs with sharpest decline in fertilizers (11.2%) and

Table 1. Perception of the farmer families regarding Covid-19

(n=120)

Statements	Yes
Main selling channel for produce was disrupted	71.60
Sources for main household income were changed/ disrupted	46.60
Your abilities to practice agriculture activities were affected	63.30
Changed prices for the agricultural output	70.00
Low availability of labour	83.30
Impact Wages of labour	75.00
Availability of agri inputs were impacted	56.60
Changes in price of agri inputs	68.30
Low access to farm credit during COVID	38.30
Impact on procurement of food grains by govt agencies	65.00
Basic banking services like deposits/ withdrawal were affected	71.60
Impact of farmers getting MSP for their produce	36.60
Impact on price level of key raw materials	35.00
Consumer sentiments/ demand were impacted	58.30
Reduction in employment activities in rural areas	55.00
Psychological health was severely impacted	33.30
Job cuts in agricultural sector	28.30

Figures denote percentage, Responses were multiple

Table 2. Perception of farmers with socio-economic variables

Socio-economic variables	Level of perception			
	Low perception	Medium perception	High perception	Total (n=120)
Age				
Up to 35 years	38.24	38.24	23.52	28.34
36-50 years	32.20	54.24	13.56	49.18
Above 50 years	29.63	48.15	22.22	22.50
Total	40 (33.4)	58 (48.3)	22 (18.3)	120 (100)
χ^2=2.97				
Education				
Illiterate	46.43	37.50	16.07	46.67
Up to middle school	0.08	63.88	19.44	30.00
Secondary school and above	28.57	50.00	21.49	23.33
χ^2=9.5*				
Caste				
General	43.33	40.00	16.67	50.00
Backward	22.50	57.50	20.20	33.40
Schedule	25.00	55.00	20.00	16.60
χ^2=5.5				
Family type				
Nuclear	38.64	40.90	20.45	36.67
Joint	30.26	52.64	17.10	63.33
χ^2=1.54				
Family size				
Up to 4 members	40.00	40.00	20.00	16.67
Between 5-8 members	32.50	45.00	22.50	33.33
Above 8 members	31.67	53.33	15.00	50.00
χ^2=1.7				

Cont...

Table 2. Perception of farmers with socio-economic variables

Socio-economic variables	Level of perception			
	Low perception	Medium perception	High perception	Total (n=120)
Size of Land holding				
Marginal Farmer (Up to 1 ha)	31.03	25.80	7.50	48.33
Small Farmer (>1-2 ha)	35.71	42.85	21.42	23.33
Semi Medium Farmer (>2-4 ha)	41.67	37.50	20.83	20.00
Medium Farmer (>4-10 ha)	20.00	60.00	20.00	8.34
χ^2=3.0				
Annual income (in Rs.)				
Up to 3 lakh	29.03	56.45	14.51	51.70
Between 3,00,000 - 6,00,000	33.33	46.66	20.00	25.00
Above 6,00,000	42.86	32.14	25.00	23.30
χ^2=4.7				
Subsidiary occupation				
Nil	31.25	55.00	13.75	66.70
Service	26.67	46.67	26.67	12.50
Small scale enterprises	44.00	28.00	28.00	20.80
χ^2=6.7				
Social participation				
Not member of any organization	30.95	53.57	15.47	70.00
Member of one organization	40.00	40.00	20.00	16.70
Member of more than one organization	53.50	25.00	25.00	13.30
χ^2=4.0				
Mass media				
Low (7-10)	38.98	49.15	11.86	49.20
Medium (11-13)	12.50	70.83	16.67	20.00
High (14-16)	37.84	32.43	29.73	30.80
χ^2=12.3**				
Extension contacts				
Low (5-7)	38.00	48.39	14.52	51.70
Medium (8-10)	23.53	58.82	17.65	28.30
High (11-13)	37.50	33.33	29.17	20.00
χ^2=5.2				

Figures denote percentage, **Significant at 1% level of significance, *Significant at 5% level of significance

insecticides (9.8%), and also the availability of seeds was down by 9.2%.

Perception of farmers with socio-economic variables: Education and mass media exposure were significantly associated with perception level at χ^2=9.5* andχ^2=12.3** while age, caste, family type, family size, size of land holding, annual income, subsidiary occupation, and extension contacts were not significantly associated with perception level of the respondents. Majority of the farmers (49.18%) of 36-50 years age category had medium level of perception. The 48.33% who were marginal farmers had low level of perception. One-fourth farmers with income between 3 to 6 lakhs had medium level of perception.

The majority of the respondents acknowledged that transport facilities were not available (71.67%). The 75% respondents were ignorant of Covid-19 and its repercussions. Substantial majority admitted that they were facing financial problems (73.33%) and it was corroborated by the survey conducted by NABARD indicating that nearly 59% of districts at all-India level indicated a negative impact on farmers' access to finance through KCC in approximately 50% of the sample districts in India, access to basic banking facilities like deposits and withdrawals was severely affected (NABARD 2020). The 61.67% of the sampled population was not able to perform agricultural activities. Furthermore, 65% of the respondents were not able to avail the medical facilities. Ojo et al (2022) observed that 90% negative influence on farm activities and income. Sarada and Kumar (2021) reported that 43% of farmers felt restricted by non-availability of cash and 25% felt that poor medical facilities for animal during the pandemic were an issue.

Table 3. Challenges and problems faced by farming families (n=120)

Statements	Yes
Transport facilities were not available	71.67
People were ignorant	75.00
Finance problems	73.33
Medical facilities were not accessible	54.26
Unable to perform agricultural activities	61.67

Figures denote percentage, Responses were multiple

CONCLUSION

The majority of respondents concurred that Covid-19 had a detrimental impact on agricultural output and, consequently, their level of income. Additionally, their profit level had significantly decreased because of the increased wastage of produce brought on by the restriction on vehicular movement, which made it difficult for them to transport their produce from the farm to the point of use. Reduced demand, declining prices, and a scarcity of labour are the issues that need to be fixed. Due to tight restrictions, the epidemic has affected every step of the chain from farm production until the final consumer. However, maintaining a smooth supply chain is essential for food security. In addition, waiving of interest on agri-term loan, construction of rural godowns, expansion of cold storage infrastructure capacities in rural areas and agricultural mechanization can be done. All of the afore-mentioned recommendations will address the difficulties and limitations that farmers are experiencing as a result of COVID-19. Therefore, agriculture is essential to ensuring the nation's socio-economic and emotional well-being both during and after the COVID-19.

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